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Sewage Research

RESEARCH IN SEWAGE CHEMISTRY, SEWAGE TREATMENT AND STREAM POLLUTION

A CRITICAL REVIEW OF THE LITERATURE OF 1936

By Harry A. Faber, H. F. Gray, W. S. Mahlie, H. Heukelekian, Willem Rudolfs, H. W. Streeter, B. A. Whisler, and E. B. Phelps, *Chairman*

Committee on Research, Federation of Sewage Works Associations

Chemistry and Biology

Material progress has been recorded during 1936 in the general field of chemical, biochemical and biological theories of sewage treatment. Important individual studies have dealt with the mechanisms, reactions and theories involved but the year has been especially marked as a period of consolidation of knowledge, of bringing together and building up the various details of experimentation into general hypotheses. It is also noted that plant-scale application of fundamental knowledge and experimentation in several directions has resulted in practical progress.

Clarification.—Several papers dealing directly or indirectly with the clarification stage of activated sludge have been published during the year. The observations and studies vary from methods to increase the rate of removal of solids and their compacting to attempts to explain the mechanisms involved in the clarification phenomena. Whitehead and O'Shaughnessy * (1) incorporated inert materials in the floc, thereby producing a remarkably brilliant effluent. When the particles were too large they were rejected by the organisms and either not utilized (organic matter) or not used to grow upon (inert).

A critical review of various views dealing with the complex phenomena of clarification by activated sludge has been presented by Theriault (1). This was followed by the publication of results, a discussion on the adsorption of activated sludge (2) and the presentation of a biozeolitic theory of sewage purification (3). Theriault in his studies focussed attention on the floc itself as the primary absorbent of finely divided and colloidal substances, apart from the embedded bacteria, secreted enzymes and microscopic animals associated with the floc. This raises an interesting question in regard to the nature of the gelatinous matrix and its functions. Theriault believes that the absorbent principle in activated sludge is a base-exchange substance, chemically similar to the zeolites employed in water purification. In an effort to throw further light upon the clarification phenomena, Heukelekian (1) studied the removal by activated sludge of certain or-

* The bibliography is arranged alphabetically and serial identification numbers are used only in the case of more than one publication by the same author.

ganic and inorganic substances similar to those occurring in sewage. He found a partial removal of infusorial earth and kaolin which could not be correlated with the clarification power of the sludge for sewage, or with the sludge index. Organic substances, such as dextrose, peptone, casein and bacteria were also removed by stirring with activated sludge, but since biological action was not precluded the action could not be ascribed to adsorption.

The question of the mechanism of clarification by activated sludge warrants further investigation. The widely different theories of various investigators, all supported by certain data, suggest that each had found at least a part of the whole truth and that a harmonizing generalization is still to be sought.

Oxidation-Reduction.—The biological oxidation of carbohydrates in the form of cellulose in the activated sludge process and trickling filters has been studied by Jenkins (1). About the same amount of cellulose was oxidized when cellulose and nitrogen, in the form of NH_4 (HCO_3), were added in the C/N ratio of 80:1 as when the C/N ratio was 8:1. Cellulose and ammonia were oxidized simultaneously, with no evidence that decomposition of cellulose preceded oxidation of nitrogen. In trickling filters more decomposition occurred with the lower ratio. As found by previous investigators a portion of the nitrogen (26% with the larger amount of N) disappeared, while with the small amount of nitrogen only 45% was accounted for in the film and in the effluents. Wooldridge and Standfast (1) reported that the initial rate of oxidation of crude sewage or of a sewage effluent was greatly increased by the presence of sludge, although the ultimate oxygen absorption value was scarcely influenced by this factor. Marked differences in the oxygen demands of various sewages were demonstrated within a few hours. The same authors (2) found that the rate of oxidation of sewage increased with the rise of temperature from 18 to 37° C., and that the optimum reaction was pH 7.3, with marked reduction of rate at pH 5.0 and 10.0, and complete inhibition at pH 4.0. Carbon dioxide is evolved in sewage and sludge oxidations but Wooldridge and Standfast found that the ratio CO_2/O_2 was much less than unity. They suggested that the ratio might increase as oxidation proceeds. Heukelekian (2) actually measured the rate of oxidation by CO_2 production and compared it with B.O.D. results. He found that CO_2 production from sewage and activated sludge was greater than oxygen consumption by the dilution methods, resulting in CO_2 to B.O.D. ratios greater than unity. With fresh solids, ratios less than unity were obtained. The differences in the ratios, using sewage, activated sludge and fresh solids, were attributed to the differences in their respective flora and fauna and pH values. The CO_2 production, on the basis of suspended solids from the returned activated sludge, was considerably lower than from sewage.

Watson has reported that in general the rate of oxygen absorption by activated sludge depends upon the condition of the sludge. A reconditioned sludge, if put into unpurified sewage, has a much larger

immediate demand. McNamee found that soluble and colloidal matter of sewage was rapidly oxidized in the presence of activated sludge. In the presence of nitrifying activated sludge the 5-hour oxygen demand of the sewage was greater than the total first-stage oxygen demand, while the total oxygen demand of the sewage was lower than the total oxygen demand observed under the conditions of the B.O.D. test. These observations probably mean that a considerable amount of the material was used to synthesize activated sludge flocs. It is concluded that a large part of the oxidation with "good" activated sludge takes place during the first few hours of contact.

From experiments on the oxygen demand of an activated sludge, Goldthorpe concluded that for arresting the absorption of dissolved oxygen by activated sludge, copper sulphate and mercuric chloride have been found most suitable. The phenomena associated with the rôle of nitrogen in biological oxidations were investigated by O'Shaughnessy and Hewitt. Their experience led them to the conclusion that only activated sludges capable of nitrification have the power to bring about denitrification with release of gaseous nitrogen. An equation suggested to envisage the action is:

$$C_6H_{10}O + 8KNO_2 = 4KHCO_3 + 2K_2CO_3 + 4N_2 + 3H_2O.$$

The effects of greatly increased filter rates upon the removal of finely divided materials and the stabilization of effluents have been so pronounced that a broader conception of the purification mechanism of trickling filter processes is imminent. Levine *et al*, studying the effect of ceramic filter media, reported that a large part of the B.O.D. reduction and a part of the sedimentation was due to the colloider action of the filter. Barritt, in experiments with milk plant wastes, found that septic tank effluents high in B.O.D. had a wide carbon-nitrogen ratio, requiring the addition of nitrogen (and probably phosphates) for good results. Muers, in experiments with laboratory trickling filters fed with a 10 per cent solution of whey in tap water, found a reduction of 90 to 95 per cent of the B.O.D. Excessive growth of the film (*Fusarium*) was checked to some extent by preliminary fermentation of the feed. Fermentation of the lactose in the whey before filtration had no ill effect. Protozoa were always abundant, but metazoa were slow in establishing themselves. When the larvae overtook the growth of the film there was a copious discharge of debris. The biological oxidation of stearic acid can be accomplished if available nitrogen, phosphorus and potassium are present. Jenkins (2) showed also that the oxidation of the stearate occurs more readily when sewage is present.

Jenks indicated that the oxidizing capacity of a bio-filter may be greatly augmented by recirculation and, to a significant extent, results accomplished were independent of the physical dimensions of the media in the bed.

The view has been held that the most important factor in biological oxidations of sewage is a series of catalysed enzymes present in either

living or dead bacterial cells or liberated by them into the liquid of the reacting system. Wooldridge and Standfast (3) discussing the rôle of enzymes in activated sludge and sewage oxidations, presented indirect results on sewage, sterilized by Seitz filtration, heat and various disinfectants. The sterilized sewages usually did not absorb oxygen when shaken in a Barcroft micro-respirometer, while the addition of crude sewage, washed sludge, bacterial cells or bacteria-free protozoa cells induced the oxidation of sterile sewage or sterile sludge. Moderate irradiation of sewage with ultra-violet light does not prevent oxygen absorption. Although protozoa possess enzymes and can oxidize the constituents of sludge, it is concluded that most of the oxidation is brought about by bacterial enzymes, the bacteria being both more numerous and generally much more active. It is probable that the activity of the living proliferating cell for certain oxidations is greater than that of the dormant cell. This was definitely shown by Streeter (1).

Colloids.—Clarification, whether by the action of activated sludge or by chemical or physical change in the fluid, is in large measure the result of flocculation of colloidal materials. Studies of the mechanism of this effect are of fundamental interest. The coagulating effects of bubbles of gas (air, oxygen, nitrogen, hydrogen) on the dispersed material of sewage have been studied by Williams. At 25° C. each of these gases produced the same amount of coagulation during a 6-hour period, but in 24 hours oxygen and air were superior. Coagulation increases with increasing temperature. Comparing the same gases for untreated and sterilized sewage, Williams and Murray found that the addition of potassium cyanide decreased the power of gas bubbles to coagulate and that this effect was neutralized by the addition of mercuric iodide. The results indicate that flocculation or coagulation of dispersed material by gas bubbles is mainly physical, although a biological effect is suggested.

Methods.—For the determination of the strength of sewage and the efficiency of treatment works the B.O.D. test is the most valuable and useful yet developed, despite interference by industrial wastes or poisons and certain other deficiencies. These deficiencies however remain to be overcome.

Measuring the oxygen absorption from air by sewage and sewage effluents manometrically by the Barcroft differential manometer Wooldridge and Standfast (4) reported that the oxygen absorption for any particular sewage was usually greater than when estimated by the usual test for B.O.D. Under the aerobic conditions of the Barcroft apparatus such gases as hydrogen, methane, hydrogen sulphide and nitrogen do not appear to be liberated during oxidation.

Heukelekian (3), by using sewage as an inoculum into phosphate-buffer water and maintaining definite dissolved oxygen concentrations in closed systems, has shown that bacterial numbers in sewage apparently increase with the oxygen tension. Simultaneously, higher B.O.D. results were observed. If this be the case in general, it may account

for many of the variations often encountered in B.O.D. determinations. In a study regarding the influence of substrate on the dilution method for B.O.D., Lea and Nichols found that the B.O.D. value of a 0.1 per cent glucose solution, using seeded bicarbonate dilution water, was far below the value obtained when more complex synthetic water was used. Lea and Nichols suggest a more complicated substratum. Any such medium, however, is still artificial. A rapid method of estimating the "strength" of solutions containing organic matter has been described by Muers. It is a modification of the procedure of Adeney and Dawson, by which the organic matter is supposed to be rapidly oxidized to CO_2, H_2O and NH_3.

Fair has suggested a new mathematical treatment, the so-called "log difference" method, to find an approximate value for K, the reaction velocity constant of the first-stage B.O.D. curve, and based upon this, an approximate value for the ultimate first stage demand L; or for greater accuracy to find a trial value of K to be employed in determining these constants by the "least squares" method.

Two modifications of the iodine method for determining total sulphides in sewage were compared by Pomeroy. The method recommended, depending upon volatilizing the sulphide into a zinc acetate solution, and determination by titration, is considered quite accurate under ordinary conditions.

Errors in the determination of moisture of wet and partially dewatered sludges by the heat drying method may be considerable because of the volatility of substances other than water. The distillation process, employing some liquid organic solvent having a higher boiling point than water, avoids this error. The use of xylene by the Dean and Stark method as applied to sewage sludges by Bach has certain disadvantages. Lumb found the perchlorethylene method described by Steward very satisfactory and free from the defects of the xylene method. Strell obtained good results by centrifuging sludge.

Activated Sludge

Activated sludge research in 1936 seems to have resolved itself into three main types of study:

1st—Investigations of bulking phenomena.
2d —Rate of oxidation studies.
3d —Details and mechanism of the process.

Bulking Phenomena.—The A. P. H. A. Committee on Sanitary Engineering, chose as their subject for investigation in 1936 "The Bulking of Activated Sludge."

In their report they differentiate bulking into two types, one the "true bulking," characterized by a flocculated sludge of high index and a slow settling rate, usually accompanied by a high volatile matter content and frequently occurring in dry weather; and the other the "rising type," in which the sludge is of a slimy de-flocculated nature with an extremely slow settling rate, usually accompanied by growths of *sphaerotilus* and the presence of carbohydrate wastes.

After reading the report one is struck by the diversity of opinions as to the cause of bulking, and the various methods of control.

Among the causes suggested in the literature are listed insufficient air, excessive filamentous growths, excessive carbohydrates, tomato seeds, peach wastes, vegetable and fruit pulps, milk wastes, phenol wastes and dry weather sewage.

Corrective measures suggested include the addition of chemicals for the control of hydrogen-ion concentration, for partial sterilization, or to weigh down the sludge particles; and varying the amount of air supplied.

Despite the diversity of opinions, and, at first glance, of the facts, the present reviewer finds considerable support for the idea that bulking is fundamentally a maladjustment of oxygen supply and oxygen demand. From this viewpoint, filamentous growths such as *sphaerotilus* are a symptom rather than a cause, which explains why bulking may occur without excessive growths, and growths may be present without serious bulking. Industrial wastes, especially those of carbohydrate nature, increase the demand. In such cases, increasing the rate of aeration is frequently a sufficient remedy. Where this fails there remains the suggestion that the aeration rate may be sufficient over-all, but insufficient at the influent end of the aeration tanks, where the demand is concentrated and where the damage may be done. This reasoning seems to be borne out by the experience of Andersen at Rockville Center, and that of Nordell, Kessler and others, on tapered aeration, which will be discussed later.

Smith and Purdy's success (see section Chemical Treatment), in controlling bulking by chlorine addition and consequent reduction of filamentous organisms, and especially their microscopic observations of the character of the sludge particles, suggest that the filamentous organisms cause the bulking, but it is significant that their control lay in maintaining a ratio between the solids in the return sludge and the amount of chlorine added. It has been suggested that the use of chlorine inhibits the bacterial activity in the early stages, so that the air supply keeps pace with the reduced rate of oxygen utilization.

This is in line with experiences at Lima, O., where E. E. Smith used chlorine quite successfully. He found that when the air/sewage ratio was reduced below 1.00 to 1.25 cubic feet per gallon, bulking might be expected, but with the use of chlorine, the ratio could be cut to 0.90.

Rhodes' experience at Hagerstown, Md. is also significant in this connection. His plant had been troubled by periodic bulkings, had an excessive aeration requirement and, when not operating efficiently, produced odors. Ferric chloride (4.0 to 7.7 p.p.m. Fe) prevented bulking and improved settling. Chlorinated copperas, (3.6 to 19.1 p.p.m. Fe) reduced necessary detention time to 3 hours (from 6 to 9 hours), reduced air requirement by one-half and was most efficient when applied to sewage just prior to or just after adding return sludge. None of these treatments, however, gave a uniformly clear effluent. The efficiency and economy of the treatment were improved by addition of

chlorinated copperas (carrying an excess of chlorine) to the return sludge just prior to mixing. The excess chlorine averaged 2.2 p.p.m. based on sludge volume.

The experience of Hodgson at Glenelg, Australia, is also suggestive. Treating a concentrated domestic sewage, 23 to 54 gal. per cap. per day, B.O.D. 328 to 772 p.p.m., at high summer temperatures he found under-aeration a primary cause of bulking. With dissolved oxygen maintained at 2 p.p.m. or over at all stages, sludge condition was normal although protozoal life was varied. *Euplotes, oxytricha, rotifera, hexophyllum* were present in limited numbers but were not considered essential, and *amoeba, arcella, nematodes, flagellates* and filamentous fungi, including *sphaerotilus* were absent. A bulking sludge was quite the opposite, with *sphaerotilus* massive and predominating.

Three-day aeration of sludge gave only temporary relief. Liming to pH 9.0 and 24-hour aeration was more successful. Paddles improved the efficacy of aeration, and even use of the paddles as fixed baffles was beneficial.

Some of the operating data of this rather unusual plant are of interest. B.O.D. was reduced from a range of 328–772 to 10.4–26.0; suspended solids to 17–25 p.p.m. Aeration ranged from 6 to 12 hours, return sludge, 25 to 64 per cent of sewage flow; air, .39 to 1.69 cu. ft. per gal. and suspended solids in aeration liquor, 910 to 2800 p.p.m.

Ardern and Lockett, on the basis of extensive operating experience in England, believe bulking to be caused by under-aeration. It would appear that maintaining a proper condition of the return sludge and a proper balance between oxygen demand and supply in the early stages of the process constitute the best control measures. This balance can be maintained either by retarding bacterial activity to keep pace with the oxygen supply, or possibly by increasing the latter. Oxygen supply means actual oxygen dissolved, not rate of aeration. It is quite possible, with a strong sewage and a highly active sludge, that the rate of solution of oxygen during the early stages may be insufficient, even in the presence of excessive rates of aeration. In such a case chlorination might be successful where increased rate of aeration would do little good.

This leads to the natural question, "What is a properly conditioned sludge?" A number of investigators have attacked this question.

Ardern and Lockett conclude that a good sludge is one that settles rapidly, filters well, has a relatively low B.O.D. and contains a preponderance of the large ciliates, with a scarcity of flagellates, amoeba and the filamentous organisms. In their studies they used six laboratory tests, as follows:

Rate of settlement
Drainability or filtrability
B.O.D. tests
Oxygen absorbed from permanganate
Dissolved oxygen of the mixed liquor
Microscopic examination

They consider the oxygen absorbed test to be of no particular value and the drainability test of value, provided greases are absent. The remaining tests are of more practical value, and the microscopic examination has never failed to give a true indication. Whitehead and O'Shaughnessy (1) employ the criterion of settling rate. A good sludge is one that will settle eight feet in one hour. Other authorities differ on this point. Mohlman's "sludge index" is a criterion of similar nature.

McNamee in his studies of oxidation of sewage by activated sludge speaks of "good" and "poor" sludge. He uses these terms with reference to settling properties of the sludge and presents data to show that although there may be practically no difference in the total oxidizing capacities when compared on a weight basis, there may be a marked difference in the *rate* of purification capacity, which justifies the use of the sludge index.

Rate of Oxidation.—Quite an amount of work seems to have been done on this subject, and a better understanding no doubt will do much to clear up some causes of the "temperamental upsets" common to activated sludge plants. We have the following pertinent statement from Whitehead and O'Shaughnessy (2). "Appreciation of the rapidity with which oxygen is absorbed by sewage liquor is essential for the proper design and successful operation of biological sewage treatment plants, particularly of the activated sludge type. . . . The rate at which oxygen is supplied in activated sludge plants is therefore the most important limiting factor in the application of the process to the complete treatment of strong sewages and industrial wastes."

The work of McNamee has been referred to in the section Chemistry and Biology. Nordell's work and use of the Odeeometer was discussed in this review last year.

In the field of practical application, Kessler, Rahlich and Smart have studied the rate of oxidation, as measured by oxygen absorption, with some suggestive conclusions. Nordell had shown that this rate decreases rapidly from the beginning of the aeration. Kessler's investigations have shown that in treating sewage of various strengths the maximum rate at the start was independent of the strength of the sewage, being dependent only upon the sludge. The rate declined progressively in such a manner that any given lesser rate was reached at a time proportionate to the strength of the sewage.

In the study of oxidation rates it is important to be able to stop the oxidation at any specified time, and this has led to the use of sterilizing agents which kill the organisms without other action on the oxidizable materials present. Kessler and Nichols, following the procedure of Beck and Palmer, used copper sulphate for this purpose, while the British investigators seem to favor the use of mercuric chloride. Heukelekian has proposed to use the rate of CO_2 production as a measure of the rate of oxidation, but after a number of experiments he concluded that "for the present, CO_2 production cannot be used for the computation of oxygen demand."

The recognition of the oxygen demand/supply ratio, has led to the use of "stepped or tapered aeration" or perhaps a better term would be "controlled aeration." As previously mentioned this can be done in several ways, such as by increasing the amount of air, by slowing down bacterial action by means of chemicals, or by limiting the amount of oxidizable material. Ardern and Lockett (2) use alumino-ferric and acid, a short period of aeration (3 to 10 minutes) followed by a short 30 minute settling period as a means of combating frequent overloading, which disturbs the oxygen demand/supply ratio. At Helsingfors the ratio is maintained by diluting the strong sewage with treated effluent at the inlet to the aeration tanks (Granqvist).

Details and Mechanism of the Process.—In addition to further discussions of the mechanism of the clarification phenomena, dealt with in the section on Chemistry and Biology, certain other details of the activated sludge process have attracted some attention. One of these is the relative merit of mechanical versus compressed air aeration. Each of the methods has its champions. The plant at Marlboro, N. J., where two identical tanks side by side could be treated with the same sewage, offered an excellent opportunity of making such a comparative study, and such a study has been reported by Ridenour and Henderson. One tank was aerated by means of a revolving brush while the other used compressed air diffused through porous tubes. The B.O.D. reduction was practically the same in both methods. With 3000 p.p.m. of suspended solids in the mixed liquor, the removals were also practically the same in both tanks. With decreasing concentration of solids, the compressed air unit was progressively more effective although the difference was not indicated by the B.O.D. results. The greatest difference in the two methods lay in the character of the sludge produced. The settling and compacting of the compressed air sludge was about three times as great as that from the brush aerator.

Distribution of dissolved oxygen was more uniform with the brush aerator. The average circulation velocities were about equal in both types, while the brush aerator gave higher velocities at the surface and bottom.

With reference to the cost of operation, it was reported that for the same degree of purification the revolving brush aerator consumed from 18 to 22 per cent less power than the compressed air aerator.

Sludge Rising.—The contamination of effluents from final settling tanks by sludge particles may be due to a number of causes. In activated sludge plants, incomplete clotting or scum formation in the aeration channels, overloading of settling tanks, or "bulking" and rising of the settled sludge mass may be responsible. Statements have been made that blanket rising of sludge and subsequent passage over the weirs is due to over-aeration. O'Shaughnessy and Hewitt considered that the gas in rising sludge, essentially nitrogen, is responsible. McLachlan states that experience has shown that to produce an over-aerated sludge requires days of aeration rather than a period measured in hours. Blanket rising is different from true bulking and may be

produced at will. It may result from over-powering good reconditioned sludge by the introduction of a stronger sewage than usual. A good active sludge when overloaded produces a deteriorating sludge and by further overloading a so-called "over-powered" sludge. A deteriorating sludge rises rapidly or does not settle, has a stale odor, with few, relatively sluggish organisms present, while an over-powered sludge does not rise for several hours, has a foul odor with few organisms. Reduced flow and aeration of an over-powered sludge changes it to a deteriorating sludge, and further aeration again to a good active sludge. The reviewer believes with O'Shaughnessy that the blanket rising is caused by nitrogen gas. Whatever the origin of the gas in rising sludge, any form of mechanical shock or agitation will serve to liberate the gas bubbles and prevent rising.

Sludge Digestion

Progress in the practice and theory of sludge digestion has been rapid and many new concepts have led to much experimentation and to radical changes in the art. In reviewing this topic for the past year it has seemed desirable to sum up at somewhat greater length than usual the present-day situation.

Mechanism and Agencies.—The mechanism and agencies of sludge digestion are biochemical in nature and their understanding entails some knowledge of the substances undergoing transformation, and of the intermediate and end products formed. The knowledge and technique gathered in the general fields of biochemistry and microbiology can be utilized with slight modifications for attacking this phase of the sludge digestion problem.

A general survey of the types and groups of substances present in domestic sewage sludge has been made. By comparatively simple techniques the occurrence and quantity of fats, cellulose, hemicellulose, lignins and proteins have been determined. A more detailed investigation regarding the identity of the various important compounds would necessitate the laborious methods of organic chemistry.

By determining the quantity of these substances after digestion has proceeded it has been possible to show that various substances have been subject to varying degrees of decomposition. Fats, constituting one of the most important constituents of fresh solids, disappear rapidly and extensively in anaerobic digestion. Celluloses and hemicelluloses, which are present less abundantly, disappear as readily but certain resistant substances, such as lignins, tend to accumulate. Proteins disappear to a lesser extent but profound changes take place in their constitution. Some of them are decomposed completely to ammonia. Others are partially hydrolyzed to amino acids and amides. Still others are resynthesized into the microbial protoplasm. All microbiological transformations resulting in degradation and decomposition are necessarily accompanied to a certain extent by synthetic processes although the extent of the latter is much more limited under anaerobic than aerobic conditions.

Regarding the transitory intermediate products, much less is definitely known. Most of the organic substances in sewage go through a definite succession of changes such as the degradation of cellulose under anaerobic conditions through the cellobiose and glucose stages and that of proteins through polypeptides-amino acid stages to ammonia. Most of these changes are continuous chain reactions so that an accumulation of the intermediate products does not take place unless the normal reaction is blocked by certain poisons. No attempts have purposely been made to block a part of the reaction in sludge digestion. In addition to testing the general concepts of chain reaction transformations, such a procedure might lead to important practical implications.

The most important of the intermediate products from the standpoint of quantity and effect are the organic acids. These arise from the anaerobic decomposition of a variety of substances commonly present in fresh solids such as celluloses, proteins, fats, etc. These acids when properly neutralized form an excellent source of food and energy for microorganisms. The free acids, even though not highly dissociated, can increase the hydrogen ion concentration sufficiently to retard microbial activity seriously. Normal digestion with sufficient ripe sludge gives little difficulty from this cause.

Beyond gross identifications, little work has been done to determine the identity of these organic acids. Quantitative estimation of the total volatile acids have been made, and constitute a valuable yard stick for controlling the digestion process. It has been shown that acetic, butyric, propionic, valeric and lactic acids are among those formed during digestion. The artificial stimulation of digestion for the accumulation and utilization of such acids might lead to profitable exploitation of sludge digestion.

In regard to the agencies responsible for digestion, little of a definite nature is known beyond the fact that bacteria and their enzymes play an important rôle in the transformation and stabilization of the organic material. The available technique in the field of bacteriology has been utilized only with partial success in determining the bacteria responsible for digestion. The enumeration of the bacteria capable of growing on plates has led to the suspicion that these organisms are not the ones actually involved in the essential transformations. Grouping the organisms into different physiological groups according to their ability to bring about specific changes in various artificial media (such as the ability to liquefy albumen, to produce NH_3 from peptones, to reduce NO_3 or SO_4) has the added difficulty that any given species may fall into two or more groups, while each group contains many species. Furthermore the changes brought about by bacteria in pure culture and in artificial media may not be similar to those brought about by these organisms in mixed cultures in their natural and much more complex environment. Bacteriological techniques, therefore, have not been as fruitful in elucidating the intricacies of sludge digestion as biochemical technique. More definite information regarding the responsible organisms would be of value and would open the attractive possibility

of replacing the more cumbersome method of inoculation with ripe sludge with the more efficient and economical method of pure culture inoculation. It would then be more readily possible to direct the process towards a desired end, whether it be for the production of some valuable substance such as alcohols, organic acids, etc., or for the usual purpose of disposal without nuisance.

The enzymatic reactions, which are intimately related with bacterial activity, are little known. There is evidence of their presence and we postulate their essential activity in converting the non-diffusible molecules such as proteins, celluloses, etc. into forms more readily assimilated by bacteria. Hydrolytic enzymes must play an essential rôle in the "liquefaction" stage, in contra-distinction to the "mineralization" stage which involves the more or less complete degradation of the liquefied or hydrolyzed substances intracellularly with the accompanying liberation of energy.

The energy liberation under anaerobic conditions is made possible by intermolecular or intramolecular rearrangement whereby one compound or one part of a molecule is oxidized while another is reduced. Energy liberation under these conditions does not necessarily entail the additions of oxygen to the molecule but merely a removal of hydrogen (dehydrogenation). It is a necessary corollary of this concept that a hydrogen acceptor be provided either by a portion of the same molecule or by an entirely different molecule. It has been suggested that water may act as an oxidizing-reducing agent in the anaerobic process.

The end products of the mineralization stage of digestion are CO_2 methane and humus. The humus or the ripe sludge can be considered to consist of the substances resistant to decomposition plus the microbial products such as the synthesized cellular material and the cellular exudates in a complex form of integration with each other. The important end product of sludge digestion besides the sludge itself is the gas produced. The volumes and composition of the gases have been repeatedly determined.

An important phase of research in sludge digestion has been the study of the effect of environmental conditions. Some valuable and practical contributions have resulted from these studies. Some of these factors will be discussed at length. This discussion deals more directly with separate sludge digestion although it also applies in the main to Imhoff tank digestion.

Temperature.—Even in summer months the temperature of sewage and of fresh solids expected in the temperate climate are far below the optimum for sludge digestion. Artificial heating to overcome the vagaries of external temperatures is beneficial. Sufficient capacity can be provided to permit a slow rate of digestion to proceed without artificial heating, but artificial introduction of heat to sludge digestion tanks is essential for successful rapid operation. Bolton reports that the digestion of excess activated sludge alone was not successful. The mixture of fresh solids and activated sludge could be digested in un-

heated one-stage digestion tanks having a capacity of 84 days or 6.35 cu. ft. per capita. There was no pH control and no stirring. Experiments with heating (80° F.) and stirring (Pruss mechanism) indicated that with 1.36 cu. ft. per capita capacity, satisfactory digestion could be obtained. The quantity of gas evolved increased to 0.71 cu. ft. per capita per day which was in excess of what was needed for the maintenance of the temperature.

Opinions and practices differ as to the most economical digestion temperature. Whitehead and O'Shaughnessy (3) place the optimum for Birmingham, Eng. at 75° F. In the U. S. some tanks are heated as high as 90° to 100° F. The optimum temperature from laboratory experiments is about 80° to 85° F. The most generally accepted method of heating is by circulating hot water through coils in the digestion tanks, although heat exchangers for heating the fresh solids prior to addition to digestion tanks and introduction of steam and hot water into the tank have been advocated. Whatever the method of heating or the temperature of the digestion tank, the development of artificial heating of the digestion tanks introduces a problem of insulation.

Seeding.—The accepted method of seeding digestion tanks is by the use of some digested sludge. There is a definite relation between the amount of ripe sludge in relation to raw sludge and the digestion time. In practice the amount of raw solids received is fixed. The digestion capacity is also fixed and in operation there is not much latitude for varying the ratio of raw to ripe sludge except by conserving as much of the ripe sludge as possible and wasting ripe sludge only after all the available liquid has been decanted. There is, however, adequate information now available upon which to design digestion capacity in terms of expected quantities of fresh solids and proposed temperature of digestion.

Aside from the quantitative relationship between the ripe sludge and fresh solids there may be qualitative differences in the seeding value of the ripe sludge in a given plant at different times as well as in different plants. At present there is no way of recognizing and controlling these variations from a bacteriological standpoint. Chemical criteria such as pH, percentage ash, B.O.D., color, etc. are of considerable value.

Banks studied heated separate sludge digestion at Palo Alto using tanks with a capacity of 1.5 cu. ft. per capita. In starting the tanks no ripe sludge or lime was used. The pH rose to 7.0 in nine months. Foaming occurred soon after starting as the sewage at that time received large quantities of cannery wastes.

At Williamsburg, Va., the separate sludge digestion tanks receive primary clarifier sludge and humus sludge from trickling filters. The pH value is maintained at 7.0 by the addition of lime. No scum or acid condition is encountered in the digester (Meisel).

Reaction.—Proper reaction, as an important factor for optimum digestion, was early recognized as a result of numerous investigations.

Too acid a reaction (below 6.6), resulting from deficiency of ripe sludge or by the introduction of trade wastes, is inimical to satisfactory rapid digestion. The optimum reaction covers a range from pH 7.0 to 7.8. However, under practical operating conditions at certain plants, satisfactory digestion is obtained with pH values of 6.6 to 6.8, and no amount of artificial control by lime addition will permanently change this reaction or aid the digestion. These anomalous cases might be explained either on the basis of the peculiarities of the wastes obtained, the particular type of flora established, or the mineral constituents of the water. It is not unreasonable to assume that the established flora differs from plant to plant and from time to time.

Digestion of Activated Sludge.—The digestion of waste activated sludge in conjunction with primary sludge introduces difficulties of a practical nature without necessarily changing the fundamental processes. The problem created is mainly due to the inherently low solids content of activated sludge, which seldom exceeds 1.0 to 1.5 per cent and is often less. This reduction of the solids content of the mixture added to the digestion tank persists throughout the digestion resulting in a thinner sludge which does not properly separate from the supernatant liquor. This difficulty has led to the design of digestion tanks for mixed sludges with much larger capacities than those receiving primary tank sludge alone. Or decantation tanks may be used to concentrate the mixed wastes or the waste activated sludge alone prior to addition to the digestion tank. The use of chemicals to concentrate the sludge does not seem to have been attempted.

Supernatant Liquor.—The disposal of the supernatant liquor presents difficulties. Returning it to the raw sewage or application to sand beds are two common alternatives. Neither is without objections. Again coagulation might offer a practicable solution.

Scum.—Although difficulties from scum formation are not as serious with separate sludge digestion tanks as they are with Imhoff tanks, yet scum frequently becomes a problem. Under certain conditions the solids in the digestion tank tend to accumulate on the top and, becoming hard and viscous, impair digestion.

The conditions which induce undue scum formation are (1) acid reaction, (2) poor seeding, (3) low temperature, (4) insufficient digestion capacity. All these are interrelated and may frequently be reduced to one single factor, namely insufficient capacity. From an operation standpoint, scum breaking mechanisms are useful to combat this troublesome phenomenon. Devices for recirculation of digestion liquor or water to aid in the submergence are also in use.

Muller claims that distribution of fresh solids in separate sludge digestion tanks is poor. He has developed a new distributing mechanism to overcome this difficulty. The sludge flows to a revolving distribution plate and is distributed like rain over the whole surface of the digestion tank. No scum is present because of the repeated new charges to the top of the tank. Two tanks were operated for 10 months, one with such a distributor and one without. The increase of gas pro-

duction with the distributor varied between 3.4 and 19.3 per cent. The CO_2 content of the gas from the tank with the distributor was low, 32.9 per cent as against 34.3 per cent in the control tank.

Two-stage Digestion.—The modern two-stage digestion tank is probably an offshoot from the earlier practice of removing digested or partially digested sludge from the digestion tank into a storage tank to obtain greater concentration of solids or to store the sludge over the winter months. The two-stage process embodies certain additional advantages in economy. Digestion starts rapidly and slows down as it proceeds. Therefore by segregating the rapid from the slower stage and providing the former with favorable environmental conditions such as temperature control, mixing, etc. in a comparatively small unit and then transferring the partially digested sludge to tanks which are not heated, covered or equipped with mixing and gas collection mechanisms, economies in the overall construction costs may be effected. Most of the gas is produced in the first tank, and this gas is collected and utilized. The rapid ebullition of gas prevents the sludge from compacting.

In the second tank, where the sludge is allowed to mature, adequate compacting can take place. Whether this separation of the phases is accompanied by development of characteristic flora for each phase is not known. A special case of two-stage digestion is initial digestion at thermophilic range followed by mesophilic digestion.

An example of a multiple-stage digestion is that of the Los Angeles County Sanitation Districts described by Rawn, Banta and Pomeroy. The tanks are so designed that the lower strata of one tank automatically pass ahead to succesively lower tanks. Primary and activated sludge, plus approximately 20 per cent by volume of digested sludge, are introduced into the tank. The average reduction of organic matter in the tanks for a 2-year period was 46.4 per cent. Of the total amount of gas 47 per cent was produced in the first stage. The weight of gas was 107 per cent of the weight of organic matter destroyed, without taking into account the weight of CO_2, NH_3 and volatile matter lost on drying the samples.

In fresh solids 98.6 per cent of the nitrogen was in the solids while 1.4 per cent was in the form of ammonium compounds or organic nitrogen in solution. In the digested sludge 56.8 per cent of the original nitrogen was in the solids while 43.2 per cent was in solution.

Battle Creek's two-stage digestion plant is described by Damoose. This plant takes care only of primary sludge. The capacity of the secondary or storage tank is larger by 40 per cent than that of the primary. The raw sludge is pumped to the primary tank, which overflows partially digested sludge to the secondary tank. The latter overflows supernatant liquor to the sewage. The primary digester is equipped with agitators. Sludge circulation is possible between the digesters in either direction.

The operation of the two-stage digestion tanks at Durham, N. C., is described by Franklin. A mixture of fresh solids and activated sludge is pumped to the digesters after the adjustment of pH with hydrated

lime. Two of the three digesters are used for the primary stage. An automatic continuous recording calorimeter is used for measuring the B.T.U. value of the gas and to check up the efficiency of the digesters. The contents of the primary tanks are circulated by means of pumps for 2 hours once in 8 to 10 days to prevent stratification. Ninety per cent of the available gas is evolved from the digestion process within 36 hours after addition of raw sludge. When a tank becomes overloaded the heat value of the gas drops and a longer period is required to obtain the major part of the gas. The gas has a thermal value equivalent to 4240 to 8350 B.T.U. per pound of volatile solids added to the digester.

Two-stage digestion is reported from Stockport, England, by Ward. The sewage contains industrial wastes. The solids are 10 to 14 days old when admitted to the digestion tanks. Scum is formed in the primary but not in the secondary tanks. Digestion of activated sludge alone gave rise to odors which were produced when the solid content of the sludge added was 5 per cent or less. This difficulty was overcome by adding the excess activated sludge to the primary settling tanks. Compressed air was used to stir the sludge during digestion without any advantage or disadvantage. Two-stage digestion is considered to have a definite advantage.

Fulton reports the operation of two-stage digestion of mixed activated and primary sludge. In starting the tanks the contents became acid (pH 5.8) but gradually digestion picked up and foaming appeared. Foaming subsided after pH value reached the alkaline side. Each tank received 7 to 8 per cent of its capacity of raw solids daily. In primary tanks no difference in results was apparent between continuous and intermittent stirring. In the secondary tanks intermittent stirring gave better separation of water than continuous stirring. A sludge with 9.7 per cent solids was obtained with either form of stirring.

Steele discusses the experiences with two-stage digestion tanks at Birmingham, Yardley Works. The seven heated tanks are charged twice a week. It is observed that humus sludge alone is difficult to digest but digests satisfactorily when mixed with raw sludge. Fermentation lagged for 48 hours after addition of humus sludge whereas with primary sludge the lag was only 24 hours. The primary tanks are charged 14 per cent of their capacity per week. The removal of more than 6 per cent of ripe sludge per week retarded fermentation. Quiet circulation of the sludge in the primary digestion tanks (½ hr. per day) helped the digestion.

Reports from West Middlesex Main Drainage Works (Mogden) indicate that digestion tanks are of two-stage type equipped with stirring mechanism and heated to 80° F. The tanks receive primary and activated sludge previously thickened.

Stirring and Circulation.—Gentle horizontal stirring, and vertical circulation by means of pumps, represent two divergent practices. Certain advantages are claimed for each. There are so many factors involved that it is difficult to arrive at a clear-cut conclusion. Stirring

devices distribute the raw solids evenly over the surface and bring them into intimate contact with the ripe sludge. This should prove to be an advantage if the normal mixing accomplished by gas and convection currents is not adequate. It is claimed that slow mixing gives a thicker sludge and a more even flow of gas. These advantages are not so apparent from the tests reported by Mohlman (1) who gives the results of Chicago experiences with large experimental heated (temp. 95° F.) separate sludge digestion tanks receiving 1 part of activated sludge and 1 part of primary sludge. One tank was equipped with stirring mechanism on top and at bottom and the other contained no mechanism. The results were as follows:

	Moisture in Digested Sl. %	Gas per Lb. Vol. Matter cu. ft.	Digestion of Vol. Matter %	Solids in Supernatant Liquor %
No mechanism	96.2	8.9	42.1	0.35
Mechanism	95.5	8.9	41.9	1.37

Stirring mechanisms are also equipped to break up the scum; this is of importance and may accelerate the rate of digestion. Vertical circulation by means of pumps frankly abandons the principle in digestion of quiescent stratification and compacting in favor of more active mixing. It does not of course follow that if a certain degree of mixing is beneficial a greater amount will be better. This seems to be borne out by the Baltimore tests reported by Keefer (1) where the sludge moisture without circulation was 94.1 per cent and with circulation system 96.4 per cent. The slight advantages gained in higher gas production (mostly CO_2) cannot compensate for the greater volume of sludge.

Garbage.—Interest continues in the disposal of garbage with sewage, with recognition of the fact that a considerable amount of garbage has always gone down the sewers, and that this quantity will probably increase in the future. Carpenter, Rogel and Grabois indicated by experimental work that ground garbage mixed with sewage sludge in per capita proportions could be successfully digested in 40 days, as compared with 25 days for sewage sludge alone. The pH value fluctuated with garbage more widely than with sewage sludge, so that adjustments were found necessary. There was no essential difference in gas production. The garbage and sewage mixtures settled readily, but the settleable solids and B.O.D. in the effluent increased, the latter in proportion to the added volatile solids.

Bloodgood found that garbage could be digested when mixed with fresh solids on the basis of per capita production (at Indianapolis) of each waste. Laboratory experiments were made with daily charges of primary and activated sludge, and garbage, the digestion being carried on at 85° F. with manual stirring once in 4 hours. The average charge was as high .42 lbs. volatile solids per cu. ft. of digestion capacity per day. Garbage solids constituted 33 per cent of the total

volatile solids added. The digested solids withdrawn with and without the garbage addition were similar in regard to percentage of solids, ash, ether soluble matter and organic nitrogen. However, the supernatant liquor from the garbage mixture had 26 per cent more total solids and 95 per cent more volatile solids than the liquor from the tank receiving primary and activated sludge. The 5-day B.O.D., and the organic nitrogen of the liquor were not increased. Garbage-sludge mixture produced more gas than primary and activated sludge mixture. It was concluded that garbage sludge mixture could be digested as readily as the raw sludges alone.

Difficulties may arise, however, in actual practice. One of these has to do with the method of dosing the garbage solids into the digestion tanks. Babbit discusses the results obtained by different methods of dosing the garbage into the digestion tanks. Adding the garbage directly to the digestion tanks disturbed the digestion process by decreasing the pH values and increasing of volatile solids. Low gas yields, with low percentage methane, and heavy scum layer (10 ft.) were observed. Admission of the garbage to the inlet end of the flowing-through compartment of the Imhoff tank gave no difficulties in operation. Active gasification was obtained, pH 7.0 was maintained and no scum layer was formed. However, garbage solids appeared in the effluent and the B.O.D. of the effluent was higher than that of the influent. Two-story, two-stage heated (90° F.) separate sludge digestion tanks receiving ground garbage and fresh solids were successfully operated, as indicated by the pH value, quantity of volatile acids and quantity and quality of gas.

In tanks actually operating with a narrow margin of capacity, the additional load in the form of garbage may give rise to difficulties. Griffin estimated that for Greenwich, Connecticut, conditions the volatile matter in the garbage would be three times the volatile matter removed from the sewage. In all the experiments reported the garbage solids have been considerably less than the sewage solids. Indications are that garbage solids in excess of sewage solids do not digest. For the above reasons the proposal of disposing of garbage with sewage at Greenwich was abandoned.

Keefer (2) concluded from a general discussion of available data that it is too soon to predict how satisfactorily and quickly garbage can be digested with sewage sludge in Imhoff and separate sludge digestion tanks.

Chemical Sludge.—With increasing use of chemical coagulation the problem of the effect of chemical sludge on the design and operation of digestion tanks is developing. Sludge treated with ordinary coagulants and dosages digests somewhat more rapidly and with lower gas yields than ordinary sludge. Owing to the hydrous nature of the chemical floc the sludge may be thinner.

Hendon gives interesting results on the digestion of mixtures of raw and chemically treated sludges. The digesters were of the two-stage type but were designed for three times the present connected

population. The chemical sludge contained 1 per cent solids, which increased to 2.5 per cent with 15 hours of storage. Good overflow liquor was obtained.

Some of the points upon which more experimental data are highly desirable are solids concentrations and compacting that may be expected, drainability and settleability, in decantation tanks, and quality of supernatant, all as compared with non-chemical treatments.

Activated Carbon.—The use of activated carbon has been shown by Lawrence and Eichenour to have a beneficial effect on sludge digestion at Liberty, N. Y. One of the digestion tanks which had a pH of 6.0 was treated with activated carbon for a period of 14 days. The pH of the tank contents increased to 6.9. An increase in the temperature of the digestion tank was also observed. From Newark, N. Y., T. J. Smith reported the following benefits from the addition of activated carbon. (1) Increase in temperature and pH of the digestion tanks, (2) increase in digestion and absence of foaming, (3) increase in quantity and quality of gas, (4) absence of odor in digested sludge.

Industrial Wastes

Industrial wastes are commonly present in sewage and fresh solids but the digestion of solids from these wastes as such has received but little consideration. The two following contributions, however, have been made. Buswell and Le Bosquet report the results from pilot plant experiments of the anaerobic digestion of distillery wastes. The slop was passed through two digestion tanks in series. The greater part of digestion and gas production was accomplished in the primary tank. Liquid from the secondary tank was put back into the primary tank for seeding and dilution. The temperature was maintained at 130° F. The gas yield was 11.0 cu. ft. per lb. of volatile solids, which compares very closely with the gas yield from sewage solids. From a raw screened slop with 3.4 per cent solids and 15,000 to 16,000 p.p.m. B.O.D., an effluent with 1500 to 2000 p.p.m. B.O.D. was obtained. Agitation of the tank contents was helpful. To a 7200 gal. capacity tank as much as 550 gal. of slop could be added daily.

The digestion of pea and cannery wastes in combination with fresh and activated sludge is reported by Warrick, Ruf and Holderby. The ripe sludge in every mixture was kept constant at 10 per cent of the total dry solids and percentage of the wastes in the mixture was increased with a corresponding decrease in the percentage of fresh and activated sludge. The digestion temperature was at 70 to 80° F. for the pea waste series and 50 to 70° F. for corn waste series. Mixtures in which the pea waste constituted 5 to 20 per cent of the total solids gave gas production curves similar to the control. With 70 to 90 per cent pea wastes the peak of gas production was considerably delayed. With increasing percentage of pea waste in the mixture the percentage of CO_2 in the gas increased and reached a maximum value of 60 per cent with 90 per cent waste. The acidity of the mixtures was likewise adversely affected by increasing percentages of pea waste. The maxi-

mum rate as well as total gas production was materially lowered with increasing proportion of corn solids. Ten per cent or more corn waste had a pronounced effect on the pH values of the mixtures. The pH value with 90 per cent corn waste did not exceed 4.7 during 99 days digestion. The odors became offensive with increasing proportions of corn waste. It was concluded that with pea wastes in excess of 40 per cent, liming and greater digester capacity would be necessary. With corn wastes increasing to 10 per cent or more, digestion may be adversely affected.

Various Treatments.—Reichle and Sander noted the effect of rotted leaves on digestion. Rotted leaves constituting 1 to 2 per cent of the tank capacity were added to a separate sludge digestion tank in which acid digestion had started. Within a few days after the addition the sludge began to produce gas normally.

Ardern reported experiments on the aerobic digestion of activated sludge. One part of seeding sludge (aerobic) to 2 parts (by volume) of activated sludge (1 per cent dry solids) were aerated. A 45 to 55 per cent reduction of organic matter was obtained in 14 days (on the basis of the activated sludge). A high degree of acidity was developed, due to nitrification, most of which took place during the first two days of aeration. Lime or sodium carbonate was used to correct the acidity, 840 p.p.m. of NO_3–N was produced from neutralized sludge and 160 p.p.m. from non-neutralized sludge.

Imhoff Tanks.—A few reports on the operation of Imhoff tanks have been made. Mohlman reports the Imhoff tanks at the Calumet Works yielded digested sludge with a moisture content of 87 per cent but that the moisture content increased to 94 per cent when activated sludge was digested. Smith reports that foaming at Elgin, Ill., was stopped once by raising the pH value of digestion tanks contents to 6.8 to 7.2 by the addition of lime. On another occasion foaming was stopped by removing all the sludge. Krum states that at Allentown, Imhoff tanks have caused more operating difficulties than any other unit of the plant, scum and foaming being two of the main problems. The best remedy is the old practice of resting or hosing down. Indications are that the uneven distribution of solids into the different Imhoff tanks aggravates the foaming in certain tanks. Schlenz has given an excellent discussion on foaming in digestion tanks. Among causes mentioned are (1) excessive loading (2) increased activity (3) objectionable organisms in sewage (4) character of sewage (5) departures of the pH from normal (6) viscosity of the liquid or scum (7) character of raw solids loading and (8) restricted area of gas vents.

Tabular Summary of Data.—Certain data from various sources are summarized in Table I, and although not complete they allow some interesting comparisons to be made. Stage digestion is practiced in more than half of the plants reported during the year. Almost all the plants have some provision for stirring and heating. The Bury results are available with and without temperature control and stirring facilities. In spite of the fact that it is not possible to attribute definitely the re-

TABLE I.—*Design and Operating Data of Sludge Digestion Tanks*

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Ref. No.	Location	Stage Digestion	Stirring Mechanism	Heating ° F.	Sludge	Capacity		Gas Yield		Raw Sludge		Digested Sludge		pH Value	
						Days	Cu. Ft./Cap.	Cu. Ft./Cap.	Cu. Ft./Lb. Vol. Mat.	Solids	Ash	Solids	Ash	Raw	Digested
51	Los Angeles, Cal.	Multiple	no	85	primary act. sl.	9.7–15.3	—			% 4.5	%	%	%		
37	Battle Creek, Mich.	yes	Turbomixer agitator	yes	primary		1.5–2.0								
39	Durham, N. C.	yes	Circulation (pump)	82	primary act. sl.			1.3–1.6	7.6–11.2	2.6	30.0				7.2
58	Stockport, England	yes	Air (occasionally)	44–62	primary act. sl.	140	5.6			5.6	28.7	4.9	42.9	7.2	8.2
40	Coatbridge, Scotland	yes	Dorr	78	primary act. sl.			0.65		5.0	38.7	9.7	54.0	6.8	8.0
57	Yardley Works, Birmingham	yes	Circulation of liquor	77.5	primary humus sl.										
32	Palo Alto, Calif.	no	Hewitt type	79–97			1.5	1.0–1.3	12–14			6.0	46.0		7.1–7.2
48	Williamsburg, Va.	no	Dorr type	80	primary humus sl.			0.6							
56	Aurora, Ill.	no	stirring	84–86	primary			.678	11.4	4.6	33.0				
45	Springfield, Ill.	no	no	94–99	primary act. sl.		2.5	.71	9.71	4.57	39.0	8.9	62.1		7.2–7.3
34	Bury, England	no	no	51–60	primary act. sl.	84	6.35	.53		3.5	28.3	3.1	27.3	6.2–6.5	7.25
34	Bury, England	no	Pruss circulation	80	primary act. sl.	23	1.36	.71	8.08	3.5	30.8	2.6	40.7	6.5	7.25
60 and 61	West Middlesex	yes	stirring	80	primary and secondary	23	—	—	—	5.0	—	5.0	—	—	—

sults to one or the other factor as an overall result of heating and circulation, the capacity was reduced from 6.35 to 1.36 cu. ft. per capita. The per capita gas production was higher with heating and circulation. The solids in the digested sludge were lower but the ash content was higher with heating and circulation.

Most of the plants are handling primary and activated sludge, the latter being wasted to the primary tank. In spite of the wide distribution of the plants reported and the variables in sewage character (trade wastes) there is uniformity in the per capita gas production, the maximum daily variation being from .53 at Bury (without heating and circulation) to 1.3 to 1.6 cu. ft. at Durham, N. C. (with heating and circulation). A daily per capita gas production of .6 to .7 cu. ft. seems to represent the average for modern tanks (with heating and stirring).

Chemical Treatment

The operation of the Shades Valley plant continues to yield interesting data on chemical treatment of sewage. Hendon reports best results when chemical sludge from the secondary tank is mixed with the influent to the primary tank after a short flocculation period. This gives a more uniform sludge of higher solids content, together with odor reduction. However, care must be taken to prevent reduction of ferric to ferrous iron. With chemical coagulation, the supernatant liquor from the secondary (unheated) digester has a much lower solids content and B.O.D. than the liquor from single-stage non-chemical digesters, the liquor containing about 175 p.p.m. of ferrous iron, which when oxidized with chlorine gives a clear liquor of less than 10 p.p.m. B.O.D.

Calvert gives an excellent review of cost data on chemical coagulation processes, compared on the basis of 1,000 lbs. B.O.D. removed, contrasted with similar data for biological processes. He indicates some advantages for chemical treatment plants operated seasonally to meet changing dilution requirements.

Baumgartner has presented an analysis of relative costs of ferric and ferrous salts under varying conditions and prices, presenting the information in the form of useful diagrams and tables. The wide range in cost shown indicates the necessity of careful consideration in the choice of material.

At Grand Rapids, Damoose (2) has found ferric chloride to be the most effective coagulant, has compared results with and without coagulant and analyzed the relative costs. His most effective dose averaged 1.12 gr. per gal.; the most effective coagulating period, 15 min.; the most effective settling period, 2 hours. In this connection it is well to call attention to the increase in removal of setteable solids by plain flocculation without chemicals which has been observed in several cases, and to suggest the desirability of more tests comparing plain sedimentation, with and without mechanical flocculation, with chemical coagulation. In chemical treatment plants it may prove advisable to operate

the flocculator mechanism continuously as an adjunct to the sedimentation process, even when chemicals are not being added.

Singleton and Frith at Atlanta found that adjustment of pH to the acid side with carbon dioxide, obtained from burned digester gas, facilitated flocculation and lowered the cost of chemicals. They found pre-settling without chemicals disadvantageous under their conditions.

The advantages of part-time treatments, either during the summer season, or to relieve peak loads, is being more frequently recognized. The use of chemicals lends itself most readily to such a program.

At Minneapolis, chemical treatment has been adopted after seven years' study because it meets most economically and flexibly the varying dilution requirements of the Mississippi River below Minneapolis-St. Paul. Bass states that the final design calls for 3 min. rapid mixing, 26 min. flocculation and 2 hours sedimentation, followed by chlorination.

Colorado Springs is to use chemical coagulation and chlorination in summer, and plain sedimentation in winter. Lowther reports the summer sewage flow to be about twice the winter flow, with ample dilution in winter and low river flow in summer; there is also a wide hourly variation in sewage flow. Chemical treatment for the 12 day hours in summer apparently will be sufficient. The design contemplates a detritor, duplicate comminutors, pre-settlement (1.4 hr.) in a primary clarifier, flash mixing (1 to 3 min.) with chlorinated copperas, flocculation (30 to 40 min.), secondary sedimentation (2 to 2¾ hr.) and final chlorination.

Ardern and Lockett are using chemical pre-treatment to carry peak loads in an activated sludge plant, in preference to incurring the capital cost of increasing the capacity of the aeration tanks. They use "aluminoferric" for coagulant, and the sewage is adjusted with acid to pH 6.4.

Thomas reported the use of continuous chlorination of sewage, on the basis of from 25 to 50 per cent of the chlorine demand, to reduce a serious nuisance in the River Avon due to septic sludge deposits. He reports that the sludge flats became non-septic and remained non-septic even during hot summer weather.

Smith and Purdy in experimental work indicated that chlorination of return sludge was useful in combatting bulking of activated sludge due primarily to fungus growths, but chlorination was useless against bulking due to a light, diffuse floc. Dosage ranged from 0.1 to 1.0 p.p.m. based on weight of dry solids. The chlorination of activated sludge requires close, accurate control to prevent over-chlorination and the destruction of desirable plankton.

Marlow reports on large scale experiments on the use of chlorinated copperas in the London sewer outfalls for odor reduction, and especially on methods of manufacturing the material at the site.

Rudolfs and Gehm have published the results of a systematic study, in the laboratory, of coagulation by ferric chloride. Employing turbidity readings to determine degree of clarification, they found that

$FeCl_3$ had two pH zones of optimum coagulation, at about 2.5 to 3.5 and 9.5 to 10.5. The exact point shifts within these zones with varying degrees of sewage composition and condition (septicity) and with concentration of coagulant. Actual comparisons of turbidity readings and suspended solids showed a fairly constant relation, while the turbidity-B.O.D. ratio was somewhat affected by the sewage characteristics. Presettling of the sewage was of no benefit in ultimate results nor in economy of coagulant ($FeCl_3$), under normal conditions. With especially weak sewages and with coagulation in the alkaline range, the presence of settleable solids was slightly beneficial.

A study of the B.O.D. of the soluble and dispersed substances in sewage and the reactions of these substances during chemical treatment gave little evidence of any alteration in state with ordinary coagulation. In the acid range, pH 3.5, ferric chloride tended to reduce the "soluble" B.O.D. by about 10 per cent in fresh sewage and by as much as 30 per cent in stale sewage. Ferric chloride alone in higher concentrations had a similar effect. In the latter case, however, the result was chiefly due to a retarded B.O.D. reaction rather than to actual coagulation of material. The rates of oxidation of soluble, colloidal and suspended materials were also separately determined and found to be of the same order. The ratio of B.O.D. to volatile however is ten times as great in the finely divided as in the soluble matter, and about twice as great in the coarse suspended as in the soluble.

Mechanical Equipment

Imhoff reports a tendency in England to discontinue the use of mechanically cleaned bar screens, and to substitute hand-raked coarse bar screens or racks. Spiegel and Reynolds have discussed the use of shredders or comminutors in place of screens. Gail suggests the substitution of zig-zag metal plates as used at Highland Park, Illinois, for coarse screens. He claims the plates require less maintenance and give no trouble from clogging.

Miller (2) has presented an excellent article on the selection of electric motors and controls for sewage works. Walraven (1) prepared a detailed article on the choice of type, and maintenance, of sludge gas engines, and described (2) the operating results of the Springfield, Illinois, installation. As more information becomes available, and with more confidence in the use of sludge gas for power generation, there is a marked tendency toward heavier, slower engine types especially adapted for this service, as contrasted with the higher speed automobile types of engine frequently used in the early experimental work.

The use of rubber lining for steel and wood tanks holding corrosive solutions, such as ferric and ferrous chlorides, is increasing. Harkins describes methods of applying, bonding and vulcanizing in place sheet rubber for this purpose. Self-vulcanizing rubber liquids and plastics have also been developed for this service.

Wyman has installed at Pasadena, California, one of the most completely successful pieces of equipment in sewage works history. This

is a Cottrell-Royster heat exchanger adapted to the destruction of odors from the sludge dryers. The mechanism is simple to construct and operate, is entirely effective, and shows very great economies over previous types of odor destructors. The equipment appears to be adaptable to the destruction of a wide variety of objectionable industrial odors as well as sewage odors.

Filtration

There is at present a great increase of interest in the trickling filter operated at comparatively high rates of from 20 to 30 million gallons per acre per day, with and without re-circulation of the filtrate in various ratios to the incoming sewage. At Minneapolis, Halvorson, Savage and Piret have been operating experimental trickling filters at 20 to 30 m.g.a.d., and suggest that at high filtration rates, colloider effect is of considerable importance and digestion is negligible. Uniformity of distribution appears to have an important bearing on results. Their studies indicate that ventilation depends largely on temperature differences between air and sewage; that when these temperatures are nearly equal, forced draft ventilation is required; and that in cold weather forced draft ventilation is detrimental. The presence of mold (*Fusaria* sp.) growths in cold weather appears to be detrimental and there was some suggestion that this might be controlled by inoculating the sewage with small quantities of soil.

At Chicago, Mohlman (2), using an experimental filter 20 ft. in diameter and 8 ft. deep, dosed with Imhoff tank effluent, operated for a year at a rate of 23 m.g.a.d. and later at 26.6 m.g.a.d. The settled sewage was applied by a 4-arm rotary distributor. Occasionally forced draft ventilation was used, also re-circulation of effluent, averaging about 15 per cent of the influent sewage. The overall B.O.D. removal averaged 74.9 per cent, and the overall suspended solids removal averaged 77 per cent. The filter removed, on the average, 3763 lb. of 5-day B.O.D. per acre per day from weak sewage with a B.O.D. of 96 p.p.m.

Levine, Luebbers, Galligan and Vaughn indicate a removal from very concentrated sewage of 5-day B.O.D. of about 4000 lb. per acre foot per day at high rates (16 m.g.a.d.) as compared with 400 lb. at 2 m.g.a.d., and state that at high rates of filtration there is apparently a considerable transformation of colloids by bio-physical and bio-chemical processes to readily settleable material which flushed out of the filters. They also tried out ceramic rings or cylinders and special ceramic blocks, as filter media, finding them satisfactory for the purpose, the smaller cylinders (¾ in. to 1 in. diameter) giving better nitrification than the larger cylinders.

Jenks has experimented with high rate filtration, using shallow filters (3 feet), re-circulating a large amount of filtrate (up to five times the influent settled sewage) and using two filters in series, the first with coarse, the second with fine filter rock. Mechanically cleaned settling basins follow each filter, each with a re-circulation sump. He claims results comparable to activated sludge effluent. Experimental sized

plants at Salinas and San Mateo are operating and producing an excellent effluent, and a plant of this type has been installed at the Camarillo State Hospital in California.

Wisely, as a result of the operation of the filters at Highland, Illinois, suggests the advisability of revolving distributors to obtain more nearly continuous and uniform application of influent, and also the desirability of re-circulation of some of the effluent to dilute and stabilize the influent.

Experimental work on trickling filters appears at present to have progressed far enough to indicate that there is a great advantage to be gained in increasing the rate of filtration from the conventional intermittent application at low rates (around 1 m.g.a.d.) up to a practically continuous high rate of from 20 to 30 m.g.a.d., provided adequate ventilation is obtained. The re-circulation of part of the effluent may possess merit, at least under some circumstances, but the amount of filtrate to be re-circulated is at present a matter of conjecture. Where large volumes of filtrate are re-circulated, as is suggested by Jenks, the added cost of larger settling basins and re-circulation pumps must be balanced not only against better oxidation and clarification, if obtained, but also against the overall construction and operating costs of other processes which produce equal or better results. There appears to be need for considerable further experimentation and economic analysis of this phase of the problem.

Trickling filter media are still subject to investigation and discussion. Levine has tried ceramic media with success. Slater at Chorley, England, has compared coke, clinker and sandstone during the past nine years, with an indicated advantage for coke. Turner calls attention to the value of anthracite coal as a filter medium, which has also been used successfully at Bradford, England, as reported by Imhoff (2).

Trickling filters have also been used in connection with activated sludge plants. Miller (1) describes experiments at Reading, England, to determine the advisability of using trickling filters to complete the treatment of a partially treated effluent of an overloaded activated sludge plant, rather than build additional activated sludge units. Rudolfs (2) describes a novel combination at Rotherham, England where half of the settled sewage goes to an activated sludge unit and half to a trickling filter, with the filter effluent then going to the influent of the activated sludge unit. This combination has given better results than the former practice at that plant of sending 600,000 gallons daily to the aeration tanks and the balance to the trickling filters, for separate treatment.

Work is also being done on enclosed vacuum filters in Germany, Holland and at Zurich. Rudolfs (3) reports that at Zurich heated air is being used for the ventilation of vacuum trickling filters.

Singleton and Frith at Atlanta found that small quantities of iron (resulting from chemical precipitation) appeared to make sewage more amenable to treatment on trickling filters, and enhanced purification. They also found a magnetite filter to be useful for final clarifica-

tion, with or without chemical precipitation of the final effluent. Their experiments on a ½ m.g.a.d. scale were performed for the purpose of determining whether chemical treatment could be used on Imhoff tank effluent to reduce the load on their trickling filters.

Chlorination

The field of usefulness for chlorine and its compounds in sewage treatment continues to broaden, often with empirical or experimental development preceding any theoretical concept. A report by Rudolfs and Gehm (2) however is of decidedly greater fundamental interest. The authors have undertaken to develop our theoretical knowledge of the action of chlorine upon sewage by some carefully controlled laboratory experiments.

Substances typical of the different groups of materials present in sewage are studied to determine the effect on chlorine demand. An interesting division of the total demand is found to be 30 per cent for the settleable material; 17 per cent for the non-settleable; 23 per cent for the finely divided, and 30 per cent for the soluble material. Data show an increase in nitrogen in the filtrate obtained from chlorine-treated finely suspended solids, and theories to explain the indicated removal of nitrogenous substance from the bacterial cell are discussed.

The reduction of microbial enemies and possibly other changes following chlorination appear to permit large subsequent increases in microbial numbers. Satisfaction of the chlorine demand requires about 7 per cent additional chlorine when split chlorination is practiced, but the same quantity (as that used for a single dose) will kill as many bacteria. In discussing the effect of chlorine on oxidation, the authors note that the effect of chloro-products seems to be limited to B.O.D. incubations of 6 days. The 5-day B.O.D. reduction on 42 samples averaged 2.4 p.p.m. on fresh sewage and 2.6 p.p.m. on very stale sewage for each 1 p.p.m. of added chlorine. Satisfaction of from 20 to 40 per cent of the chlorine demand led to about the same apparent B.O.D. reduction as complete chlorination, so that the calculation of B.O.D. removal per p.p.m. of added chlorine may show great variation. This correlates with earlier work to show the more marked effect of chlorine upon the soluble and semi-soluble portions of the sewage.

Chlorination apparently retards carbon oxidation for the first 5 days of incubation, but the amounts oxidized with or without chlorine were equal after 10 days incubation. Carbon dioxide production was temporarily retarded, indicating that the chlorine oxidized or combined with the nitrogenous material present and temporarily reduced oxidation of the carbonaceous material. This bulletin warrants thorough study since an attempt is made to correlate several hypotheses and to clarify or modify the basic conception of the action of chlorine in sewage.

Chlorine for Disinfection.—Chlorination of trickling filter effluent is necessary at Allentown, Pa., according to Krum, because the effluent is discharged into the Lehigh River which is the source of the water

supply for the City of Bethlehem. Weekly analyses showed that a chlorine residual of 0.35 p.p.m. in the effluent of the final settling tanks produced an average reduction of 99.92 per cent in the total count and of 99.99 + per cent in *B. coli*. The total count, 1500 per cc. and the *B. coli*, 10 per cc., were lower than the pollution load of the stream.

Barton and Krebs studied the effect of chlorinated effluents on the B.O.D. test. By careful neutralization of excess chlorine with N/40 sodium sulphite only slight interference from chlorine derivatives was found. Sodium thiosulphate, depending on the amount added and apparently on the acidity of the sample, always increased the apparent B.O.D. Theoretical reactions are given.

Thomas has presented unusual data on the chlorination of crude sewage as practiced at Bristol, England. These tests were conducted on each of nine outfall sewers which, by discharge into the River Avon, have created obnoxious odor and nuisance troubles. Seven principal sewers were subject to tide-locking daily, and by chlorination it was attempted to delay putrefaction until aerobic purification occurred. Applied through diffusers at a rate equivalent to 25 or 50 per cent of the chlorine demand, generally 8 a.m. to 11 p.m. daily, chlorination treatment was continued from May to the end of September. Such partial satisfaction of the chlorine demand had a definite but incomplete effect on the odor nuisance and prevented the formation of septic sludge banks. Equipment did not permit the application of greater doses of chlorine, but it is proposed to continue the experiment with more adequate satisfaction of the chlorine demand.

Chlorine and Sludge Bulking.—Smith and Purdy conclude from microscopical observation that either diffuse floc structure, fungus growth, or a combination of the two may cause bulking in activated sludge. Under the microscope, they observed the effect of a variety of toxic materials on a fungus-laden aerated sludge. Chlorine, in proper proportion, appeared to shrink the protruding fungus strands in the floc without destroying the normal plankton associated with sludge.

A number of plants have reported upon the control of bulking by partial disinfection (See Activated Sludge Section).

Chlorine in Chemical Coagulation.—With the rapid advance in the use of chemicals in coagulation, chlorine and chlorine compounds are finding an increased field of usefulness. Chlorinated copperas provides a flexible system in which iron and chlorine are independently variable and the latter is therefore available for the usual functions of disinfection, preserving oxidation-reduction conditions. In several of the developments noted in the section on Chemical Treatment, this feature of dual or multiple functions of chlorine is prominent. Baumgartner, assuming that in coagulation ferric iron in whatever combination is of uniform efficiency, finds that under present market conditions, chlorinated copperas is the most economical form in which iron can be applied.

Odor Control.—While the use of ferrous chloride, made by the chlorination of scrap iron, has to a large extent superseded chlorine itself in odor control, Hosegood finds it advantageous to chlorinate the tank effluents at San Bernardino, Cal., in the trickling filter siphon tanks. He fails to report whether this treatment is of any help in reducing the chlorine dosage required for final disinfection of the filter effluent. Such advantage was found at Culpepper, Va. Wisely finds prechlorination, of 10 p.p.m. with a residual through the tanks, relieves odors about a heavily loaded plant, at which final effluent chlorination is necessary to control stream conditions (fungus).

Industrial Wastes

Milk Wastes.—Apparently the only publication on the subject of milk wastes treatment which has aroused any great interest in the past year is the report by Barritt covering work done at the Rothamstead Experiment Station in England. This report has been abstracted or more or less completely reported in several American publications.

Barritt recommends that milk wastes be pretreated in a septic tank before dosing on a trickling filter in order to remove the butter fat, which may be a serious cause of filter clogging. This is rarely a factor in American plants where milk wastes usually originate from skimmed milk. The use of the septic tank is apparently a backward step in milk wastes treatment, for this method has long ago been tried and found to be attended by serious odor and digestion troubles.

Barritt mentions that an alternative is to use two filters operating in series and to change the order of dosing when the first one shows signs of clogging. The clogged filter then becomes unclogged when operating as the second in the series. Barritt does not suggest, however, that the trickling filter can be replaced as the principal means of milk waste treatment.

In New York, Roberts points out that one of the best methods of attacking the creamery waste problem is that of cutting down the amount and strength of the waste at its source. By improved plant operation the amount of waste may be reduced as much as 50 per cent. He also mentions a new development, showing promise, which consists of removing lactose by yeast fermentation, with the commercial recovery of alcohol and the lactose-albumin-yeast precipitate, which may be used for feeding.

Levine, Nelson and Goresline have shown the value of a short dosing cycle in the treatment of creamery wastes. They report a 95.5 per cent reduction in oxygen consumed for a 2½ min. cycle, an 89.7 per cent reduction for a 10 min. cycle, and an 81.7 per cent reduction for a 22 min. cycle, while using quartzite. With fine materials such as cinders the length of dosing cycle was of little significance.

Warrick and Beatty state that results in Wisconsin confirm previous conclusions that the trickling filter is the best method of treatment.

Wisely was faced with a problem at Highland, Illinois, where an existing Imhoff tank installation was totally incapacitated by the discharge of milk plant wastes, constituting 55 per cent of the volume of the normal sewage flow, to which there was to be added the wastes from a rehabilitated brewery. The situation might probably be classed as industrial rather than domestic. A complete redesign, including sludge digestion and trickling filters, gave adequate relief. Damn and Bock describe the use of copper sulphate (2 lbs. to 250 cu. ft. of wastes), obtaining a good floc; the settled wastes were then filtered through a back-washed sand filter. The filtrate was clear but highly putrescible. It is difficult to see any advantage in this process, as the copper content would probably interfere with any subsequent biological treatment.

Sulphite Wastes.—Merryfield has studied the very difficult wastes resulting from sulphite pulp manufacture. These wastes average about 2,000 gal. per ton of pulp, and the oxidizable matter averages about one ton per ton of pulp. Typical sulphite waste has 117,000 p.p.m. solids, practically all soluble, and the 5-day B.O.D. ranges from 16,000 to 25,000 p.p.m. The best promise of ultimate solution of this problem appears to lie in utilization of the wastes for by-products such as cattle feed, fertilizer and fuel. Pending such utilization, ponding and aeration appear to be helpful, but there is need for large scale experimentation on the treatment of these wastes.

Benson and Partansky have compared aerobic and anaerobic decomposition of sulphite wastes in the laboratory, and find that under aerobic decomposition the ultimate end products are carbon dioxide and water; under anaerobic decomposition the end products are carbon dioxide and methane, and the process is extremely slow, requiring several months for completion. Lignin is decomposed very slowly, but its oxygen demand is but one-fifth that of the crude waste. Under certain controlled conditions, with inoculation of special organisms, the wood sugars can be converted into butyric and acetic acids in two days; the acids can then be recovered by distillation, leaving only the relatively stable lignins.

Warrick says that the outstanding development in this field in 1935 was the installation of the Howard process for reclaiming pollutional substances in sulphite wastes on a mill-scale basis. It has an efficiency of 75 per cent or better in the reduction of the high B.O.D.'s of these wastes.

Tanning Wastes.—Little progress has been reported in the development of methods of treating tannery wastes. Strell (2) emphasizes the difficulty of treating tanning wastes, particularly because they interfere seriously with biological processes. He claims that some tannery wastes require a dilution of 1 to 25,000 to eliminate the detrimental effects of the chrome wastes. He suggests the use of mechanical devices, secondary chemical treatment, and final chlorination. It is difficult to understand the value of chlorination in treating a waste which in itself inhibits biological activity.

Warrick and Beatty describe results in Wisconsin, pointing out that considerable progress has been made. In one plant the first attack was to distribute the wastes evenly over the full 24 hours. In another the only pre-treatment before mixing with domestic wastes is a 20-mesh rotary screen unit. Sludge from tannery wastes was successfully digested when mixed with domestic sewage sludge if the concentration of the former did not exceed 40 per cent. Chemical precipitation, it is stated, may be a promising preliminary treatment.

Eldridge found that in one tannery the lime wastes should be treated separately, using a coagulant and sedimentation, while in another plant it was best to combine the lime wastes with the other wastes for treatment.

Cannery Wastes.—Results of cannery wastes treatment as reported by Warrick and Beatty indicate that pea canning wastes are the most difficult to treat. Forty plants in Wisconsin use ferrous sulphate and lime (3¼ and 7¼ pounds per 1,000 gallons of pea canning wastes). It is relatively easy to overload activated sludge plants with pea canning wastes. Not more than 20 per cent of pea canning solids can be readily digested with domestic solids. Alum and lime are used successfully in treating kraut wastes. For all canning wastes trickling filters provide a high degree of treatment. The per cent efficiency drops off rapidly with increase in loading, but this is less apparent with preliminary aeration, indicating that the latter may be a distinct advantage. One plant screens and aerates (2 hours) the canning waste before mixing it with domestic sewage.

Packing House Wastes.—An overloaded plant treating packing house and domestic wastes at Sioux Falls was modified after a period of operation of an experimental plant. The revised plant, as reported by Estabrook, provides for ferric chloride treatment of the packing house wastes before treatment with the domestic wastes. The plant consisted originally of 4 acres of trickling filters 8 to 9 feet deep. To this installation has been added an activated sludge tank for treatment of the effluent of the trickling filter units. The plant is so designed that the packing house wastes, which constitute 50 per cent of the sewage flow, or the domestic sewage can be treated independently either through the activated sludge plant or through the filter plant. The results obtained from this plant will be watched with considerable interest.

In experiments by Levine, Leubbers *et al* on the treatment of packing house wastes on deep coarse-rock aerated filters at high rates of filtration (7 m.g.p.a.p.d.) it was demonstrated that 2,200 to 2,700 pounds of B.O.D. could be removed by filtration in place of the customary 360 pounds per acre foot per day.

Levine calls attention to the fact that a considerable portion of the B.O.D. reduction by filtration and post-sedimentation may be attributed to flocculation of the colloids by the filter and that this action was particularly noticeable at the high rate 8,000,000 to 16,000,000 gallons.

Beet Sugar.—Eldridge reports on extensive experiments on the treatment of beet sugar mill wastes at Bay City, Michigan. He found that lime treatment of combined flume and process wastes was not economical; plain sedimentation for 2 hours, with continuous sludge removal, reduced the suspended solids in the flume waste 90 per cent and the B.O.D. 35 per cent; for process waste alone, coagulation with lime was warranted. On flume waste, grit chambers with continuous grit removal were needed. The addition of Steffens waste to combined flume and process wastes gave good results when flocculated for 15 min. and settled for 1½ hr. with continuous sludge removal, and with the use of small amounts of lime at times, 99 per cent of the suspended solids and 45 per cent of 5-day B.O.D. was removed. Vacuum filtration was applicable to the sludges and to the concentrated lime slurry. Biological filtration was not justified except in extreme cases where stream dilution was limited. Further studies are required on the treatment of Steffens wastes with by-product recovery as an objective.

Miscellaneous.—Sciver suggests that industries should adjust their wastes to a pH range between 7 and 8, to reduce interference with treatment processes and to prevent damage to structures and equipment. Especially foul wastes should be chlorinated, and chemical precipitation may be required in some cases. He also suggests the desirability of equalization of the rate of discharge of such wastes into the sewers.

The Textile Foundation has compiled and published in 1936 a survey of available information concerning the treatment of textile wastes. Wastes from the various mills differ widely in their treatment requirements, but in general chemical precipitation followed by either mechanical filtration or biological treatment appears to be necessary.

It is pointed out by Powers that even in Michigan the brine from oil fields creates a serious disposal problem. He remarks that in contrast with other wastes the only treatment for chlorides is dilution.

Kalibina reports that phenol wastes decomposing in a stream disappear more rapidly in summer than in winter. Traces are more difficult to destroy than are larger quantities.

Stream Pollution

During the past year, the most important developments in the United States with reference to stream pollution and its control have been the rapid crystallization of public sentiment favoring a concerted governmental effort to solve the problem and the practical advances made in this direction through interstate cooperation.

Legal and Legislative.—On the legislative side two general movements, one originating in national sportmen's and wild life protective associations and the other among civic and business organizations in the Ohio River valley during the year 1934, enlisted widespread support throughout the country and led to the introduction of several bills in the United States Congress designed to bring about a more active participation of the Federal Government in stream pollution control. The first of these two movements found expression in the Lonergan Bill,

providing for the permanency of the National Resources Committee and for giving this committee wide power in stimulating and actively promoting waterways sanitation measures in the various States. The second movement finally centered itself in the Barkley-Vinson Bill, which was passed by both the House and Senate but failed of enactment through being recalled in the Senate for further consideration. This bill provided for creating a new division of stream pollution control in the Public Health Service and for giving this division sufficient funds to assist the States in carrying out their own programs of corrective measures, either singly or collectively through interstate compacts or treaties.

In this connection, it may be noted that during the last session of Congress an Act was passed authorizing the Connecticut River valley states to enter into a treaty for joint regulation of pollution in this river system. Under an amendment of this Act, similar authority was extended to the 14 states in the Ohio River watershed. A joint treaty commission is now being organized by the governors of several of these Ohio River states, with a view to drafting a compact and submitting it to their respective legislatures for ratification.

Definite progress has been made in the completion of a tri-state agreement between New York, New Jersey and Connecticut for controlling pollution of the waters surrounding metropolitan New York and its environs. Under the terms of a compact between these three states, an Interstate Sanitation Commission has been established. In January, 1936, the New York legislature passed and the Governor signed an Act authorizing the appointment of four commissioners from that state and defining the powers, duties and territorial jurisdiction of the commission.

An extensive printed record (U. S. Senate), of hearings held before the Senate Committee on Commerce in February, March and May, 1936, on the various stream pollution control bills introduced into Congress, as above noted, contains information concerning the extent and the present status of stream pollution throughout the country. In connection with the testimony, it was estimated by Velz that, of the 128 millions of total population of the United States in 1935, 64 millions were sewered and 24 millions served by sewage treatment. The net effect of treatment, however, reduces the total pollution equivalent of this population by only 6 millions, leaving an equivalent of some 58 millions discharging sewage into the inland and coastal waterways of the country. Mr. Velz estimated that, assuming a 50 per cent reduction in the total sewage pollution through treatment applied to the entire sewered population, the total cost of such a program would approximate $750,000,000. If amortized over a 25-year period, the annual cost, including interest and carrying charges, would amount to $39,700,000, or 31 cents per capita of the whole population.

Industrial Waste Pollution.—In other testimony submitted at the Senate hearings, the importance of industrial wastes as an element in the total amount of polluting matter discharged into streams was

emphasized. In the New York metropolitan area alone, according to Holmquist, the wastes from 100,000 industries are discharged daily into the coastal waters of this district. In a memorandum submitted by Hoskins, it was estimated, from the results of surveys by the Public Health Service, that the total amount of organic pollution originating in industrial wastes exceeds that of the domestic sewage contribution in the Ohio River watershed and is 85 and 92 per cent, respectively, of the latter in the Illinois and upper Mississippi river basins. These figures indicate that the total organic pollution contributed by industry is roughly equal to that contributed as domestic sewage.

In this connection, the results of a recent survey of industrial wastes in New Jersey, as reported by Rudolfs, are of particular interest. From these results, it was estimated that the quantities of wet sludge produced by the industries over the whole state amounted to 700,000 tons per year, as compared with 900,000 tons of sewage sludge. The "population equivalent" of these industrial wastes was estimated at about two-thirds of the total population of the state.

Purification in Impounded Rivers and Lakes.—Owing to the economic situation, intense interest has been manifested by German engineers and chemists in the possibilities of utilizing impounded rivers and lakes as an integral part of sewage purification schemes. Imhoff and Mahr have been among the leaders in this movement and have been largely instrumental in showing the possibilities of natural sewage treatment in German rivers. Notable among the working systems developed have been those in the Ruhr and Wupper rivers, where remarkable results have been obtained through the controlled dispersion of sewage into lakes formed by impounding these rivers. These systems are, in a biological sense, somewhat closely related to the fish ponds which have been used for several years past in Germany for the treatment of settled sewage. Interesting descriptions of the largest installation of this kind, located at Munich, have been given by Falck and by Schillinger. The sewage of 700,000 persons, well clarified and diluted with three volumes of pure water, is discharged through ponds having a total area of 550 to 575 acres. Falck states that one acre of pond can treat the settled sewage of 800 to 1200 persons and may produce 1600 pounds of healthy carp per year.

In discussing the practical utilization of natural purification in connection with sewage disposal, Imhoff points out that judicious introduction of sewage into streams, in concentrations such that rapid self-purification can take place, may be more satisfactory than construction of a large number of individual disposal plants along a stream course. As aids in self-purification he lists: (1) dams, where velocity is checked, water surface increased and sedimentation may occur with decreased oxygen demand; (2) turbulent sections where atmospheric oxygen is replenished; (3) artificial dilution with pure water in badly contaminated streams; (4) artificial aeration by air injection or mechanical agitation; (5) flushing or jetting with auxiliary water, whereby violent agitation aids in oxygen absorption, and (6) dredging bottom deposits.

Mahr notes the variable biological purification accomplished in Hengstey Lake, which was built to retain iron sludge discharged by the Lenne River into the Ruhr. He also shows how to calculate the amount of oxygen which may be available in a given lake of known dimensions, flow, etc., to meet oxygen demand requirements. In this connection, he adds that in a polluted lake the very fine suspended solids must be removed as completely as possible. Mechanical filtration of sewage, though unusual at present, has given favorable experimental results at the Wupperverband.

Discharge of Sewage into Tidal Waters.—The problems incidental to discharging crude sewage into tidal waters have received much attention for many years, dating back to the classic study of New York Harbor by Black and Phelps nearly 25 years ago. A novel large-scale development in a similar problem has been described by Thomas in the historic river Avon at Bristol, England. (See Section on Chlorination.)

Basic Research.—Experimental studies of natural stream oxidation have been continued at the Cincinnati station of the U. S. Public Health Service. The results of an extensive series of experiments on the effects of variations in depth, temperature and velocity of flow on rates of atmospheric reaeration in flowing streams of pure water were published early in the year. From these experiments it was concluded that the rate of absorption of atmospheric oxygen at the water surface, which is the primary factor governing the rate of reaeration of the underlying body of water, appears to be practically independent of the volume of water, but is influenced by temperature, oxygen saturation and degree of surface agitation. Velocity of flow was shown to exert a powerful effect on the reaeration rate with velocities exceeding about 10 feet per minute, which appeared to mark the point of transition from laminar to turbulent flow under the experimental conditions. For velocities less than 10 feet per minute, the rate of reaeration was observed to follow closely the laws of hydrodiffusion, as shown originally by Black and Phelps in connection with their studies of New York Harbor.

That the presence of sewage, or of sewage sludge, appears to retard the rate of absorption of atmospheric oxygen by flowing streams of water has been indicated by the results of further experiments carried out at the Cincinnati station. Parallel observations with various substances known to be present in sewage and which alter the surface tension of water in which they are present have shown similar retarding effects. Among the substances tested have been soaps, oils, fatty derivatives, urine and feces, all in concentrations roughly the same as ordinarily found in sewage. These observations have thrown some light on the possible reasons for the behavior of sewage in this respect and the entire series of experiments has given a very significant indication of the two-fold burden imposed by sewage on streams, namely, increasing the oxygen demand and retarding the recovery of atmospheric oxygen to support natural oxidation.

From France has come very recently an interesting monograph, by Leys, dealing with a study of rates of oxidation and of oxygen recovery in a small canalized tidal river, the Aa, located in northern France and flowing into the North Sea. After reviewing basic studies of the subject by the British Royal Commission on Sewage Disposal and the United States Public Health Service and noting the contributions by Frankland, Phelps, Adeney and other workers, the author discusses the results of his measurements in the River Aa, with particular reference to the applicability of the Phelps biochemical oxidation formula, which, following certain British writers, he designates as "Phelps' rule," to the progressive decrease in B.O.D. in the laboratory test and in a polluted natural stream, and likewise the applicability of formulae and methods developed by Phelps and Streeter for calculating, from laboratory B.O.D. tests, progressive rates of oxidation and atmospheric reaeration in polluted streams.

From the results of his observations, of which he cites typical examples, the author concludes: (1) that when due allowance is made for disturbing factors (inflowing dilution, intermediate pollution, sedimentation, etc.) the course of progressive oxidation conforms to Phelps' rule in the stream as in the laboratory; (2) that the first-stage oxygen demand is the most rational measure of the pollution of waters; (3) that comparison of the first-stage B.O.D.'s at any two points in a stream, separated by a distance corresponding to a time of flow of one to three days, affords the optimum procedure for a stream survey; and (4) that the method of calculating reaeration as applied by Phelps and Streeter to large American rivers is also applicable to a smaller stream like the River Aa.

In several German papers published during the past year, considerable interest has been manifested in the same quantitative methods of studying natural oxidation and reaeration as dealt with by Leys in his monograph. A very practical reason for such an interest is evidenced by the thoroughness with which German engineers and chemists are studying the possibilities of utilizing more fully and skilfully the natural purification capacities of their rivers and lakes in connection with extensive stream sanitation programs. This tendency merits attention from engineers in the United States, who are faced with similar problems on an unprecedented nationwide scale.

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STUDIES OF SEWAGE PURIFICATION

VI. BIOCHEMICAL OXIDATION BY SLUDGES DEVELOPED BY PURE CULTURES OF BACTERIA ISOLATED FROM ACTIVATED SLUDGE

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The research studies of the activated sludge process of sewage purification being carried on by the Stream Pollution Investigations laboratory of the United States Public Health Service at Cincinnati, Ohio, under the direction of Senior Sanitary Engineer J. K. Hoskins, include an investigation of the fundamental mechanism of the process. During recent years there has been intensive study of the activated sludge method of sewage treatment and many theories of the fundamental mechanism of the process have been proposed. In our studies of the total purification accomplished by activated sludge treatment, those portions of the purification which, after various periods of aeration, may be ascribed to (1) biochemical oxidation, and (2) adsorption, which necessarily includes material utilized for the synthesis of new sludge solids, have been investigated. A study has also been made of those biological, chemical and physical factors which facilitate or deter these basic phenomena of the process of total purification.

To avoid the confusion of involved results, each report as far as possible will deal with only one phase of the process and the data relative thereto. The present report will be confined to a study of the biochemical oxidation of organic matter occurring in sterilized natural sewage and in synthetic sewage when treated with active sludges developed by pure cultures of bacteria isolated from treatment plant activated sludge. In this report it will be shown that bacteria isolated from normal activated sludge can be made to reproduce similar sludge in pure culture and that this pure culture sludge exhibits oxidation characteristics similar to those of normal activated sludge.

Review of Literature. Edwards[1] has reviewed activated sludge theory and Theriault[2] has recently presented considerations on the rate and mechanism of sewage clarification. Streeter[3] summarized the work on rates of natural oxidation and showed that the oxidation reaction is proportional to the biochemical oxygen demand and follows the equation expressed by Theriault,[4]

$$X_t = L\ (1\text{–}10^{-Kt}) \qquad (1)$$

where

X_t = the B.O.D. oxidized in time t,
L = the initial total B.O.D.,

and

κ = a velocity constant of 0.1 at 20° C.

This low-rate biochemical oxidation reaction has been assumed to hold for all sewage-sludge oxidation reactions. Higher rates of biochemical oxidation have not been demonstrated conclusively up to the present time and observations indicating higher rates of oxidation usually have been ascribed to immediate or chemical demand.

The first study of rates of oxygen absorption by activated sludge was published by Grant, Hurwitz and Mohlman.[5] In this pioneer work the authors concluded that the rate of oxygen absorption for activated sludge was fairly uniform, that the rate was proportional to the organic (volatile) matter of the sludge and that this rate for Chicago, North Side, activated sludge averaged about 7.0 milligrams of oxygen per gram of sludge per hour. They calculated the oxygen absorbed required to oxidize sewage by subtracting mean oxygen absorption values for activated sludge alone from the corresponding values for sludge plus sewage.

Theriault and McNamee[6] determined the rate of disappearance of oxygen in a sludge taken from an artificial stream channel and aerated in a closed system. It was found that the rate of oxidation for this sludge was much higher than could be accounted for by the biochemical oxidation rate in diluted sewage or natural waters. This high rate of oxidation was explained by them on the basis of two simultaneous unimolecular reactions, the first of these representing the normal biochemical oxygen demand and the second the so-called "immediate" oxygen demand. The expression representing the *reaction* is:

$$Y = L_1 (1\text{–}10^{-K_1 t}) + L_2 (1\text{–}10^{-K_2 t}), \qquad (2)$$

where

Y = the oxygen demand in time t in days,
L_1 and L_2 = constants for the total first stage demand, due respectively to biochemical oxidation and immediate demand,
K_1 = the velocity constant for the normal biochemical demand, equals 0.1.
and K_2 = the velocity constant for the immediate demand.

The higher rate oxidation (L_2), in these experiments, was practically complete in 20 hours and represented about 20 per cent of the total first stage demand ($L_1 + L_2$). The authors ascribed tentatively this high rate "immediate" demand to enzymatic action, and ruled out the possibility that it might be due to a high rate biochemical oxidation reaction.

Kessler and Nichols,[7] using a dilution method and short periods of observation (six to ten minutes), showed that the deoxygenation rate of sewage-activated sludge mixtures decreased rapidly during the first few hours. They observed that the maximum rate of deoxygenation of these mixtures was apparently dependent upon the sewage strength (B.O.D.). Furthermore, using Nordell's original empirical expressions, they found a fairly constant relation between the total oxygen

used at the maximum rate by activated sludge-sewage mixtures and the 5-day B.O.D. of the sewage being treated by a given activated sludge. The factor for this relation varied from 6.0 to 13.0 for various activated sludges. This is an important observation because it suggests that the deoxygenation reaction in sewage-activated sludge mixtures is a biochemical one in which the sludge organisms are the agents that oxidize sewage organic matter at rates very greatly increased over those which occur in sewage alone. The experiments of Woolridge and Standfast,[8] also reported by Topley,[9] showed that when sewage was added to activated sludge there was an increase in the rate of oxygen absorption over that observed in activated sludge alone or in sewage alone. These experiments also indicate a more rapid biochemical oxidation of sewage organic matter by activated sludge than occurs in diluted sewage or in streams.

Goldthorpe[10] obtained rates of oxygen absorption by activated sludges from 0.021 to 0.173 milligrams of oxygen per gram of sludge per minute. In three experiments he determined the oxygen used by the sludge alone and immediately afterward the oxygen used by the sludge diluted with tank effluent. The data obtained were as follows:

MILLIGRAMS OF O_2 ABSORBED PER MINUTE PER GRAM OF SLUDGE

Experiment Number	4	5	6
Sludge + tank effluent (1 : 2)	0.173	0.095	0.124
Sludge alone	0.0259	0.029	0.023
Number of times rate was increased by addition of tank effluent	6.7	3.28	5.4

This illustrates the importance of the liquid substrate B.O.D. upon the rate of oxygen utilization of the sludge mixture. Goldthorpe's Huddersfield, reaerated, concentrated sludges apparently have very little dissolved food material in their liquid substrate. Consequently their rates of oxygen absorption are very low. When tank effluents, which still have considerable B.O.D. or dissolved organic food material present, are added to these sludges, the rate of oxidation increases tremendously as is illustrated in these experiments.

Heukelekian[11] studied oxidation rates in activated sludge-sewage mixtures by determining the carbon dioxide produced. He confirmed Wooldridge and Standfast's observations that the oxidation rates in sewage-activated sludge mixtures were generally higher than occurred in the sewage and sludge separately. He also observed that in some cases a definite retardation of the oxidation rate took place when sludge and sewage were mixed. Activated sludge, however, showed a more rapid rate of oxidation than fresh solids even though the fresh solids contained a greater amount of oxidizable material. These experiments indicate again that when activated sludge with its established massive aerobic flora is aerated, high biochemical oxidation rates are obtained.

McNamee[12] determined the rates of oxidation in sludge alone and in mixtures of sludge plus sewage, using the same sludge in each case

and carrying out the tests simultaneously. He assumed that the oxidation of the sludge at the same temperature and pH would be the same in each case and that the difference between the results obtained would represent the oxidation of the sewage by the activated sludge. From his studies with three sludges he concluded that the soluble and colloidal matter in sewage is oxidized much more rapidly than has been realized and that a large part of the oxidation required for the stabilization of the oxidizable substances present in sewage occurs during the first few hours of contact with "good" activated sludge.

Butterfield[13] reviewed that portion of the literature of activated sludge which deals with the significance of the bacteria in this purification process and reports the isolation of a zooglea-forming bacterium from activated sludge. This zoogleal organism, in pure culture, in sterilized sewage under aeration produced a floc which simulated activated sludge. This pure culture floc was shown to bring about, during a 3-hour aeration interval, a 41 to 84 per cent removal of the oxidizable material present in sewage. Such an extensive purification in such a short period suggests that this organism, or organisms of this type, are of very definite importance in this process. This purification was measured by determining the total amount of oxidizable material removed from the sewage without reference to the mode of its removal. It may have been adsorbed by the pure culture sludge, it may have been oxidized biochemically by the massed bacteria in the sludge, or both of these factors may have played a part in the purification process during the 3-hour aeration intervals.

Experimental Work

Methods. Data will now be presented showing the portion of this total purification accomplished by pure culture sludges which can be attributed to biochemical oxidation.

1. Isolation of Bacterial Cultures.—In isolating cultures for this study, an effort was made to select organisms from good activated sludge which appeared to make up a marked and, in some cases, a major proportion of the bacterial content of the sludge. A number of cultures have been isolated from sludge produced in the Station experimental plant and from activated sludges developed in regular plant installations in two other locations. The procedure followed in making the isolations was essentially the same as that previously used and described by one of us (Butterfield[13]). The fundamental characteristics of the bacteria thus isolated suggest that they all belong to the same general group of organisms as the zooglea-forming bacterium previously described. These cultures were isolated and propagated in synthetic media and in sterilized sewage. Ample precautions were taken in each instance to insure the purity of the cultures employed. Three different strains of zoogleal bacteria were used in these experiments. One of these strains was isolated from the Station experimental plant while the other two were obtained from two separate samples of activated sludge from the Lancaster, Pa., plant.

2. Substrates.—Sterile substrates were essential for the development of pure culture sludges. Two kinds of substrate were employed: (*a*) natural sewage sterilized by steam pressure in the autoclave, and (*b*) synthetic sewage, *i.e.*, solutions simulating natural sewage.

(*a*) *Natural Sewage.*—Sterilization by heat was adopted as the most satisfactory procedure for obtaining a sterile natural sewage. While it is recognized that this procedure changes the natural condition of the sewage, experiments which have been conducted have shown that it altered the sewage less than other methods of sterilization which were available and that the sewage sterilized thus was adequately suitable for the development of good activated sludge. To determine definitely the difference which might exist between sludges developed on sterilized sewage and sludges developed on portions of the same sewage left in its natural state, the following experiments were carried out. A mixture of good activated sludge and sewage was collected and 8 liters were placed in each of 2 aeration vessels, labelled *A* and *B*. Aeration was continuous at the same rate in both vessels except for 30-minute periods each day when the sludges were allowed to settle. At this period each day 5 liters of supernatant were withdrawn from each and in *A* this was replaced with 5 liters of fresh natural sewage while in *B* it was replaced with an equal amount of the same sewage which had been sterilized by heat and cooled prior to use. After this procedure had been carried on over a period of 48 days, through 41 such changes, the residual sludges were tested. These tests included suspended solids determinations, ash analyses and determinations of purification efficiency when the sludges were dosed with aliquot portions of the same natural sewage unsterilized. The purification efficiency was measured (by tests fully described later in this text), in each case after ½, 2, 4 and 24 hours aeration by the total oxidizable material removed from the supernatant, by the amount of pollutional material oxidized biochemically, and by the amount of oxidizable material adsorbed by the sludges. The agreement between the results obtained from the two sludges was excellent, in no instance differing by more than 5 per cent. This finding was considered a very definite indication that sewage sterilized by heat could be safely employed in our studies.

(*b*) *Synthetic Sewage.*—The development of sludge in sewage under aeration has been universally observed. The source of this sludge has been to a great extent a matter of conjecture and theory. In sludge developed from normal sewage the source might readily be the solids present altered somewhat by aeration and physical changes, or this sludge development might be aided by biological growth or by the precipitation of dissolved and colloidal constituents of the sewage. To be able to observe accurately the influence of pure cultures of bacteria in sludge production and in the oxidation of pollutional material by such sludge it was pertinent, in at least a few tests, that these bacteria be permitted to develop in solutions containing essentially the same dissolved constituents as sewage but which were entirely free from detritus and suspended substances of any description. Under such conditions

in a solution perfectly clear and free from all undissolved particles, sludge production should be readily observed and, if produced, could be definitely attributed to the activity of the bacteria present in pure culture. A stock solution of such characteristics was prepared and used in certain of our tests. The composition of this synthetic sewage was as follows:

Peptone, Difco, Bacto grade	0.3	gram
Meat Extract, Liebigs	0.2	gram
Urea, C.P. grade	0.05	gram
Disodium hydrogen phosphate, C.P.	0.05	gram
Sodium chloride, C.P.	0.015	gram
Potassium chloride, C.P.	0.007	gram
Calcium chloride, C.P.	0.007	gram
Magnesium sulphate, C.P.	0.005	gram
Water, distilled	1000	ml.

After sterilization this substrate was perfectly clear and had a hydrogen ion concentration of pH 7.3 to 7.4. The mineral salt content was approximately the same as that of sewage. The urea content was calculated to be about the same as that of domestic sewage, basing the calculation on Hawk and Bergeim's[14] data for the average amount of urea in urine excreted per capita per day and assuming the average daily pumpage of water per capita as the normal dilution. Sufficient peptone and meat extract were added to the solution to make its biochemical oxygen demand approximately the same as that of a strong domestic sewage. The pure cultures of bacteria being studied in these tests developed a well organized floc under aeration in this synthetic sewage in from 24 to 48 hours after inoculation. This floc would continue to accumulate under the conditions of the tests until a well developed sludge was present. Microscopic examination of these flocs revealed that they were composed principally, if not entirely, of closely packed masses of bacterial cells surrounded by a gelatinous matrix.

3. Production of Pure Culture Sludge.—In developing the pure culture sludges for use in this series of experiments the procedure was the same with sterilized natural sewage and synthetic sewage. Eight liters of sewage were placed in a 10-liter serum bottle which was equipped with a diffuser ball and inlet and outlet tubes for continuous aeration under aseptic conditions. The entire set-up was placed in the autoclave and sterilized under steam pressure. After cooling and standing for at least 24 hours, tests for sterility and hydrogen-ion concentration were made. If the reaction was not between pH 6.8 and 7.4, it was adjusted with sterilized dilute phosphoric acid or sodium hydroxide. The sterile substrate was inoculated then with a pure culture, usually 1 ml. of broth culture to the 8 liters, and aeration was started at once. As soon as a well formed floc had developed, settling for 30 minutes was allowed and 5 liters of supernatant were siphoned off through a sterile siphon. The 5 liters withdrawn were replaced with the same amount of sterile sewage and aeration was resumed. This procedure of withdrawing the supernatant and adding fresh food was repeated once

daily, except Sunday, until sufficient sludge had developed to provide material for the desired tests. This usually required from 10 days to 3 weeks. The pH of the supernatant was determined at each change and the reaction of the sterile liquid added so adjusted that the pH of the resultant mixture would be in the desired range of 6.8 to 7.4. The adjustment invariably required the addition of sterile dilute phosphoric acid, never alkaline solutions, as these cultures always produced an alkaline reaction.* Suspended solids determinations of the mixture were made from time to time to determine when sufficient sludge had developed for the tests.

4. Preparation for Experiment.—After thoroughly mixing the 8 liters of pure culture sludge developed as described above, 1-liter portions were poured into each of two 1-liter cylinders. The sludge in the two cylinders and that remaining in the 10 liter bottle was allowed to settle for 30 minutes and the amount of supernatant that could be removed without disturbing the settled sludge was determined. This amount varied from 625 ml. to 900 ml. for the liter cylinders. For illustrative purposes, suppose that 800 ml. could be removed, then this amount was siphoned from each of the liter cylinders and a proportionate amount, in this case 4800 ml., was siphoned from the 6 liters remaining in the 10-liter bottle. Eight hundred and twenty-five ml. of Formula C[15] dilution water were added to one cylinder, 825 ml. of the test feed (sterilized natural sewage or synthetic sewage) were added to the other and 4950 ml. of the same feed were added to the 10-liter bottle. Immediately after mixing, 25 ml. portions were removed from each cylinder and the large bottle for pH and suspended solids determinations. The sludge mixtures in the cylinders were transferred to two special high form 4-liter aeration bottles, which were clamped to the closed system aeration apparatus.

Aeration was started simultaneously in the 10-liter bottle and samples of supernatant were removed for the determination of total purification at the same time intervals that the closed-system aeration bottles were examined.

The analyses made for each experiment include:

(1) Dilution method B.O.D. determinations for periods of 2, 5, 7, 10 and in the last four experiments, 15 and 20 days, on:

(*A*) The old supernatant removed,
(*B*) The initial feed added.

(2) pH, suspended solids, and ash determinations on initial and after 24 hours aeration samples of:

(*C*) Sludge-dilution water mixtures in closed system aeration bottle (*i.e.*, Control—for aeration method B.O.D.).

* These cultures did not oxidize ammonia compounds to nitrites or nitrites to nitrates. It is reasonable to assume that if a balanced inoculation had been made including the nitrifying bacteria, the by-products of the combined oxidations would have tended to keep the reaction neutral. Additional experiments with the nitrifying bacteria in pure culture and in combination with the carbonaceous oxidizers are contemplated.

(*D*) Sludge-feed mixtures in closed system aeration bottle (*i.e.*, sample for aeration method B.O.D.).

(*E*) Sludge-feed mixtures in 10-liter open system aeration bottle (*i.e.*, sample for total purification).

(3) The determination of the gaseous oxygen initially and after various periods, usually ½, 1½, 3, 5, 10 and 24 hours on (*C*) and (*D*).

(4) Dilution method B.O.D. for the same incubation periods as in (1) and after the same aeration periods as in (3) on the supernatant from (*E*).

As in this study we are dealing with pure culture sludge fed with sterile sewage (natural or synthetic), all dilutions made up for B.O.D. determinations by the dilution method were seeded with stale settled sewage to insure a common inoculation and uniform results. The results obtained under (2)(*E*) and (4) dealing with the total purification accomplished are not presented or discussed in this paper which is confined to biochemical oxidation alone.

5. Apparatus and Technique for Aeration Method B.O.D. Determinations.—The apparatus and technique developed by Theriault and Butterfield[16] for determining the B.O.D. by aeration in a closed system is ideally suited for our study. Figure 5, which shows an assembly of this apparatus, is presented in the appendix. The cam shaft *D* driven by an electric motor imparts a reciprocating motion to the plunger in the mercury U-tube. This alternately increases and decreases the air pressure on the aeration line connecting one limb of the U-tube with the aeration bottle. On the upstroke the lower valve *E* acts as a seal and air is drawn in through valve *V*. On the down stroke the ball valve *V* closes and bubbles of air are forced into the liquid. With a cam shaft speed of about 150 to 175 r.p.m. very satisfactory aeration can be maintained in the apparatus. Four replica of this apparatus were set up in a 20° C. constant temperature room and all the experiments in this paper have been carried out at that temperature. Details of the technique for the collection and analysis of the gas samples from this apparatus are given in the appendix.

Experimental Data

The oxygen required for the oxidation of the control aeration mixtures in seven different experiments for various periods is shown in Table I. Table II shows the corresponding oxygen requirements for the feed aeration mixtures in the same experiments. The control and feed mixtures in each experiment were aerated simultaneously and examinations were made at the same time; the data are presented in separate tables simply for convenience. These tables contain in addition, corollary information regarding the cultures employed, the amount of pure culture sludge produced at the time of the test, the quantity of supernatant withdrawn and of fresh feed or dilution water added, the nature of the substrate feed added, and the 5-day biochemical oxygen demand, as determined by the excess oxygen dilution method, of the old supernatant and of the substrate feed added.

TABLE I.—*Oxidation in Control Aeration Mixtures*

Oxygen used when pure culture sludge suspension in synthetic or sterile sewage substrate is aerated but not fed

x = Pure culture sludge. y = 1-day old supernatant substrate. d = Formula C dil. water.

Exp. No.	Culture	P.p.m. Susp. Solids = x	P.p.m. 5-day B.O.D. of y	Composition of Aeration Mix (Liters)	Mgm. O_2 Used per Liter in Indicated Time in Hours					
					½	1½	3	5	10	24
1	Z-4	1420	17.6	$x + .375y + .625d$	7.6	8.9	13.2	17.8	—	39.1‡
2	Z-4	1632	16.2	$x + .375y + .625d$	6.1	6.9	11.3	18.7	—	52.1‡
3*b*	Z-1	773	13.8	$x + .09y + .91d$	7.7	10.1*	—	15.9†	—	23.2
3*a*	Z-1	843	13.8	$x + 1.0y$	11.3	15.8*	—	20.7†	—	35.8
4	Z-9	2644	14.5	$x + 0.1y + .9d$	5.3	9.9	13.5	32.2	35.9	48.1
5	Z-9	1560	15.0	$x + 0.1y + .9d$	12.0	12.8	14.8	18.5	25.2	38.6
6	Z-9	2428	10.6	$x + 0.1y + .9d$	8.0	11.7	17.4	19.6	37.0	60.8
7	Z-9	1632	11.4	$x + 0.1y + .9d$	9.2	5.1	17.1	15.2	22.9	34.4

* Two hours. † Four hours. ‡ Twenty-two hours.

TABLE II.—*Oxidation in Feed Aeration Mixtures*

Oxygen used when pure culture sludge suspension in synthetic or sterile sewage substrate is fed immediately before experiment and aerated

x = Pure culture sludge. y = 1-day old supernatant substrate. z = Substrate feed added.

Exp. No.	Culture	P.p.m. Susp. Solids = x	P.p.m. 5-day B.O.D. of z	Substrate Feed z	Composition of Aeration Mixture (Liters)	Mgm. O_2 Used per Liter in Indicated Time in Hours					
						½	1½	3	5	10	24
1	Z-4	1420	287	Sterile sewage	$x + .375y + .625z$	32.4	56.4	77.0	93.1	—	151.0‡
2	Z-4	1632	345	Synthetic sewage	$x + .375y + .625z$	37.1	86.2	118.2	139.7	—	210.4‡
3	Z-1	877	220	Sterile sewage	$x + .09y + .91z$	28.4	64.5*	—	91.4†	—	182.4
4	Z-9	2868	142	Sterile sewage	$x + 0.1y + 0.9z$	26.6	50.6	70.2	84.2	111.7	156.0
5	Z-9	1728	170	Synthetic sewage	$x + 0.1y + 0.9z$	34.7	69.6	92.6	113.0	131.0	153.9
6	Z-9	2544	170	Synthetic sewage	$x + 0.1y + 0.9z$	20.3	50.0	80.4	103.4	136.5	216.6
7	Z-9	1632	142	Sterile sewage	$x + 0.1y + 0.9z$	29.6	46.0	63.4	79.6	97.7	138.3

* Two hours. † Four hours. ‡ Twenty-two hours.

Discussion and Interpretation of Results

In these experiments the pure culture sludge has been considered as of negligible volume and as merely suspended in the substrate liquor. It is appropriate to consider the sludge as entirely separate from the substrate liquor because the pure culture suspended sludge is largely organized living agent. The substrate liquor in these experiments includes old supernatant containing the pure culture suspended solids, the fresh feed liquor and, in the controls, dilution water. For convenience in discussing these results

let x = the pure culture suspended solids in one liter of mixed supernatant liquor,
y = one liter of old supernatant substrate,
z = one liter of fresh feed liquor,
d = one liter of dilution water,
p = fraction of y remaining,
q = fraction of z or d used.

Then the experimental set-up for a control sludge aeration mixture and a fresh feed-sludge aeration mixture necessary for one experiment may be represented as follows,

Bottle A—Fed aeration mixture $= x + py + qz$.
Bottle B—Control aeration mixture $= x + py + qd$.

As $x + py$ are equal in each mixture and qd has no biochemical oxygen demand then for a given time interval the difference between the oxygen requirements of the fed aeration mixture and the control mixture, A–B, is produced by the increment of sterile sewage added, qz. While any increase in the oxygen requirement of the fed aeration mixture, A, can be attributed definitely to the addition of the feed, qz, it cannot be ascribed to the oxidation of the added feed alone without further consideration.

It is recognized that at any period of examination there are three sources from which the bacterial mass may draw material for oxidation; (1) from organic material originally derived from the substrate but now held adsorbed in the floc; (2) from dead bacterial cells also held in the floc; and (3) from material dispersed in the substrate. In successive time intervals from this period of examination the material drawn from these respective sources will vary and the variation will increase as the time interval between observations is increased. Thus the amount drawn from (1) may affect the amount drawn for replacement from (3) and this will affect in turn the bacterial birth and death rate, or the amount of (2) available for oxidation at the next examination. Under the conditions of our experiments, however, for short time intervals the amount of organic matter drawn and oxidized from (1) and (2) is independent of the amount originally present in or drawn from (3) and depends upon the quantity and condition of the sludge x at the start.

The oxygen requirement of the component, $x + py$, of the mixture $x + py + qz$, (A), cannot be determined separately when it is in the mixture. Without such a determination three possibilities exist in regard to the oxygen requirements of the component, $x + py$, of the mixture A, in the presence of added feed, qz, as compared with its oxygen requirement in mixture B in the absence of qz; (1) that the oxygen requirement of $x + py$ is increased and its satisfaction is accelerated by the presence of qz in A; (2) that the oxygen requirement of $x + py$ is decreased and its satisfaction is retarded by the presence of qz in A; or (3) that the oxygen requirement of $x + py$ is the same in A as it is in B and is satisfied at the same rate in both mixtures.

In considering possibility (1) if the oxygen requirements of $x + py$ were higher in A than they were in B, then in accordance with known laws, it would follow that the quantity of x or $x + py$ would decrease. As a matter of fact in a long series of observations the quantity of x or $x + py$ has never decreased but has always increased. Hence there could be no increased oxidation of $x + py$.

With regard to possibility (2), such an effect if it actually occurred

would tend to decrease the real differences between the oxygen requirements of *A* and *B*, or to decrease the indicated oxygen requirement of the added substrate, *qz*, which had been satisfied. Thus this assumption, if true, would act as a safety factor for any deductions which might be made regarding accelerated oxidation produced by the pure culture sludges.

Considered from another angle, in these tests with the exception of experiments 6 and 7, which will be discussed later, the pure culture sludges had been subjected daily to the same treatment which was given in the test. This is particularly true for experiments 4 and 5 where the added substrate, *qz*, a synthetic sewage, could be, and was, exactly reproduced from day to day. Accordingly it is reasonable to presume that the residual $x + py$ at the end of any test period was substantially the same as the $x + py$ present at the start of such test.

Consequently, as possibility (1) cannot be true and (2) if true would tend to decrease the magnitude of the results and serve as a safety factor for any deductions made it appears logical and sound to assume in interpreting the results of these tests that the difference between the oxygen requirements of the fed aeration mixture and of the control aeration mixture, *A–B*, represents substantially for the given time intervals the biochemical oxygen demand of the added substrate, *qz*, as produced by the pure culture activated sludge under aeration.

Data, which have been obtained with natural activated sludge, to prove that $x + py$ is oxidized at the same rate in *A* as it is in *B* will be presented in a later paper on oxidation by natural activated sludge. Such data for pure culture sludges were not obtained as the large quantities of sludge necessary for such experiments are extremely difficult to produce and maintain under pure culture conditions.

This method * of determining the oxygen required for the oxidation of the added substrate by the sludge has been used throughout these experiments. In one experiment (No. 3) two different controls and a feed mixture were all aerated simultaneously. One control contained the sludge suspended in .09 liter of old supernatant liquor and .91 liter of dilution water. The second control contained the same quantity of sludge suspended in 1.0 liter of old supernatant liquor. Each control has been used separately with the feed-sludge aeration mixture. The results with one control have been designated as Experiment 3*a* and with the other as Experiment 3*b*. This designation for the experiment has been used throughout this paper. It will be shown that using the method of calculation introduced here, the results for the oxidation of the total substrate in the feed-sludge aeration mixture check remarkably well when obtained with these two different control set-ups. In Table III the results showing the oxygen required to satisfy the B.O.D. of the added increment of substrate for each experiment are recorded. These results are obtained by deducting the values given in Table I (oxygen required to oxidize the control aeration mixtures) from the

* This method is valid for determining the oxygen required to oxidize sewage only if the sludge control is a portion of the same sample used to treat the sewage, and if the absorption tests are carried out simultaneously as will be shown later.

TABLE III.—*Oxidation of Added Increment*

Oxygen used to oxidize the increment of substrate added

(Mgms. O_2 used by feed culture minus mgms. O_2 used by the control)

x = Pure culture sludge. y = 1-day old supernatant substrate. z = Substrate feed.

Exp. No.	Feed Mixture (Liters) 1	Control Mixture (Liters) 2§	Added Increment (1)–(2) (Liters) 3	5-day B.O.D. of Added Increment	Mgms. O_2 Used in Oxidizing Added Increment in Indicated Time, Hours					
					½	1½	3	5	10	24
1	$x + .375y + .625z$	$x + .375y$	$.625z$	179.7	24.8	47.5	63.8	75.3	—	111.9‡
2	$x + .375y + .625z$	$x + .375y$	$.625z$	215.6	31.0	79.3	106.9	121.0	—	158.3‡
3*a*	$x + .09y + .91z$	$x + 1.0y$	$-.91y + .91z$	169.5	17.1	48.7*	—	70.7†	—	146.7
3*b*	$x + .09y + .91z$	$x + .09y$	$.91z$	200.0	20.7	54.4*	—	75.5†	—	159.3
4	$x + .1y + .9z$	$x + .1y$	$.9z$	127.8	21.3	40.7	56.7	52.0	75.8	107.9
5	$x + .1y + .9z$	$x + .1y$	$.9z$	152.6	22.7	56.8	77.8	94.5	105.8	115.3
6	$x + .1y + .9z$	$x + .1y$	$.9z$	152.6	12.3	38.3	63.0	83.8	99.5	155.8
7	$x + .1y + .9z$	$x + .1y$	$.9z$	127.8	20.4	40.9	46.3	64.4	74.8	103.9

* Two hours. † Four hours. ‡ Twenty-two hours.

§ The necessary quantities of dilution water that were added to make the controls up to one liter have been omitted from this column because they do not enter into the calculation.

corresponding values given in Table II (oxygen required to oxidize the feed-aeration mixtures). It will be noticed that the values in Table III for the oxidation of the added increment are considerably larger than the values in Table I for the oxidation of the sludge suspension plus a portion of the old supernatant substrate. This great difference illustrates the tremendous importance of the B.O.D. of the substrate feed on the oxidation rates of sludge aeration mixtures. The significance of the effect of the substrate feed on oxidation rates is more readily observed by referring to Fig. 1 where the results for a typical experiment (No. 1) are graphically presented. These results also illustrate the marked efficiency of the pure culture sludge in the oxidation of sewage.

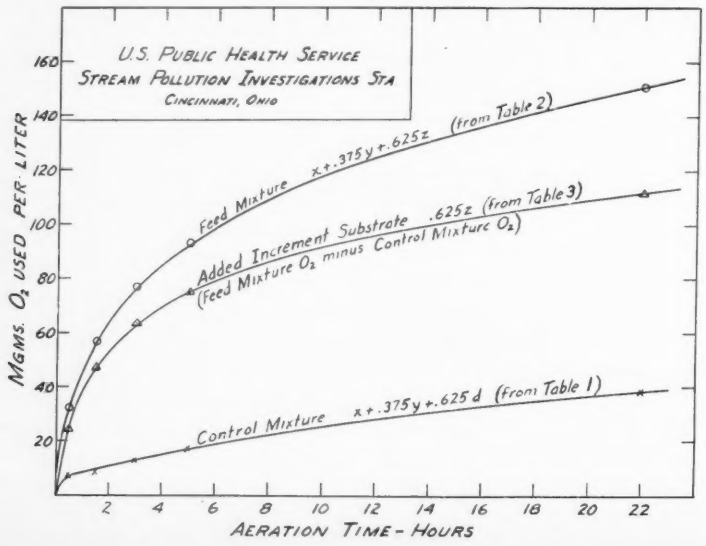


FIG. 1.—Oxidation in pure culture sludge-substrate aeration mixtures. Experiment 1.

TABLE IV.—*Percentage of the 5-day B.O.D. of the Mixed Supernatant Substrate Oxidized When Aerated with Pure Culture Sludge*

Exp. No.	Pure Culture Sludge Developed on	Substrate Feed Added for Test	Percentage of 5-day B.O.D. Oxidized in Indicated Time in Hours					
			½	1½	3	5	10	24
1	Sterile sewage	Sterile sewage	13.8	26.6	35.7	42.1	—	62.5 ‡
2	Sterile sewage	Synthetic sewage	14.4	36.7	49.5	56.1	—	73.4 ‡
3*a*	Sterile sewage	Sterile sewage	9.2	26.1 *	—	37.8 †	—	79.0
3*b*	Sterile sewage	Sterile sewage	10.6	27.2 *	—	38.0 †	—	79.5
4	Sterile sewage	Sterile sewage	16.6	31.9	44.5	40.7	59.4	84.3
5	Synthetic sewage	Synthetic sewage	14.9	37.3	51.1	62.0	69.4	75.7
6	Sterile sewage	Synthetic sewage	8.1	25.1	47.8	54.9	65.2	102.1
7	Synthetic sewage	Sterile sewage	16.0	32.0	36.2	50.5	58.7	81.4

* Two hours. † Four hours. ‡ Twenty-two hours.

From the data shown in Table III the percentage of the 5-day B.O.D. of the added substrate oxidized by the pure culture sludge after various periods of aeration have been calculated and are presented in Table IV. Typical oxidation curves expressed in these percentages during the 24-hour aeration period are shown in Figure 2. An average of about 50 per cent of the 5-day B.O.D. of the added substrate was oxidized during a 5-hour aeration interval. This rapid rate of oxidation is the more remarkable when one considers that it is carried on by bacteria in pure culture undoubtedly more restricted in their food habits than a grossly mixed culture would be. While definite information in regard to the food habits of these bacteria have not been obtained it is known that they do not oxidize nitrogen compounds to nitrites or nitrates.

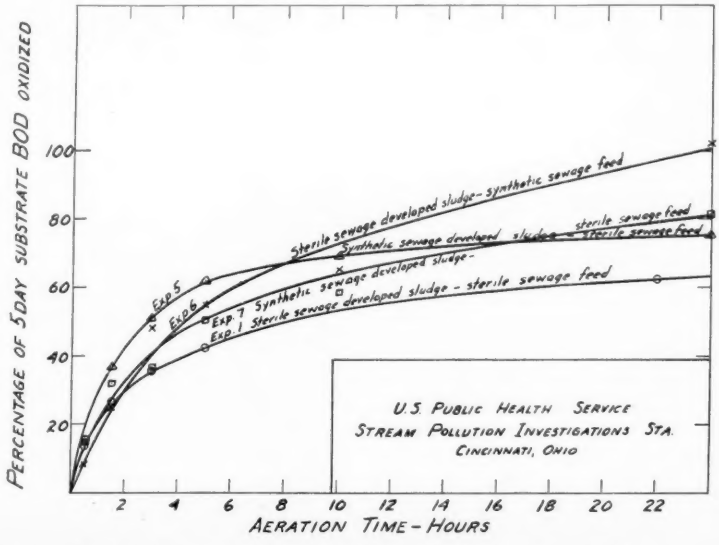


FIG. 2.—Percentage of 5-day B.O.D. of total substrate oxidized.

As the B.O.D. of y was uniformly low in all of these mixtures it is a legitimate inference that most of the oxygen utilized by the mixture, $x + py$, was required to oxidize dispersate or solute condensed or absorbed on the sludge, x. While the fraction of y and its B.O.D. was very low, corrections for the oxidation of the y component were estimated on the basis of the observed oxidations for the added substrate. These estimates varied from 0.1 to 1.1 p.p.m. after ½ hour aeration and from 1.0 to 4.5 p.p.m. after 24 hours for all experiments except 3*a*. In experiment 3*a* all of the y component was left in the control and the estimates in this case for the aeration periods given were 3.7 and 13.8 p.p.m. The application of these corrections provides for an estimation of the oxygen required to oxidize the sludge alone and of the oxygen required to oxidize the mixed supernatant, $py + qz$. While these corrections may seem to be meticulous and so small as to be unnecessary they have been used.

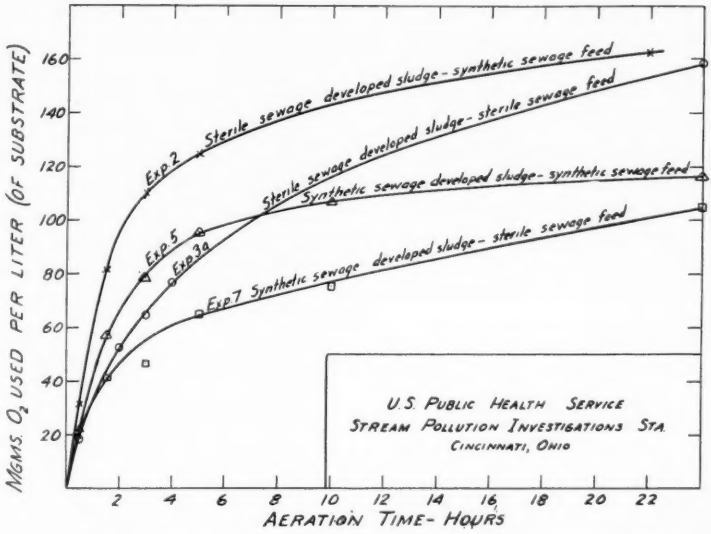
TABLE V.—*Milligrams of Oxygen Used to Oxidize One Liter of Mixed Supernatant Substrate by Pure Culture Sludge*

y = 1-day old supernatant. z = Substrate feed added.

Exp. No.	B.O.D. of Mixed Supernatant Substrate			Mgm. O_2 Used per Liter in Indicated Time in Hours					
	2-day	5-day	10-day	½	1½	3	5	10	24
1	109.3	185.9	—	25.7	49.3	66.2	78.1	—	116.0 ‡
2	174.3	221.7	—	31.9	81.5	109.9	124.4	—	162.8 ‡
3*a*	157.6	201.2	230.1	18.5	52.6 *	64.5 ||	76.5 †	—	158.8
3*b*	157.6	201.2	230.1 §	20.8	54.8 *	65.4 ||	76.0 †	—	160.4
4	90.0	129.3	135.3	21.5	41.3	57.6	52.6	76.8	109.0
5	113.0	154.1	205.7	22.9	57.5	78.7	95.5	107.0	116.6
6	112.9	153.7	205.4	12.4	38.6	63.5	84.4	100.2	156.9
7	89.8	128.9	135.3	20.6	41.3	46.7	65.1	75.6	104.9

* Two hours. † Four hours. ‡ Twenty-two hours. § Eleven days.
|| Estimated from 2 and 4 hour results.

Table V shows the oxygen used by pure culture sludge to oxidize one liter of mixed supernatant substrate. The values in Table V differ from the corresponding values in Table III only by the small estimates for the oxidation of py. Figure 3 shows several typical substrate oxidation curves plotted from data in Table V. Here the marked efficiency of the pure culture sludges in the oxidation of pollutional material is again definitely apparent. Regardless of whether the sludge was developed on sterilized natural sewage or on synthetic sewage it was equally effective in oxidizing either synthetic sewage or sterilized natural sewage. The only difference noted was that the oxidation of the synthetic sewage appeared to be completed more rapidly. This, indeed, would be expected, for all of the oxidizable material in the synthetic sewage was in solution and readily available for bacterial oxidation.


MGMS. O2 USED PER LITER (OF SUBSTRATE)
AERATION TIME- HOURS
Exp 2 Sterile sewage developed sludge - synthetic sewage feed
Exp 5 Sterile sewage developed sludge - sterile sewage feed
Exp 3a Synthetic sewage developed sludge - synthetic sewage feed
Exp 7 Synthetic sewage developed sludge - sterile sewage feed
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STREAM POLLUTION INVESTIGATIONS STA.
CINCINNATI, OHIO

FIG. 3.—Typical oxidation curves of supernatant substrate by pure culture sludge.

It seems worth while to observe here that sludge was developed to the extent of 1560 and 1632 p.p.m. respectively in experiments 5 and 7 where synthetic sewage was employed. The development of this pure culture activated sludge in a synthetic sewage containing all materials in true solution and free from suspended particles can be certainly attributed to the activity of the bacteria present in pure culture. Microscopic examinations of the individual flocs of this sludge showed that they were composed of closely packed masses of bacterial cells. The results obtained (Tables III, IV and V) show definitely that these sludges have the same oxidation efficiency as sludges developed in sterilized natural sewage.

To show the average performance of these pure culture sludges in oxidizing the B.O.D. of the substrate, the mean number of milligrams

TABLE VI.—*Mean Milligrams Oxygen Used to Oxidize Substrate B.O.D. In all pure culture sludge experiments for various aeration mixture units*

Aeration Time, Hours	½			1½			3			24			Mean
	Mean Mgms. O_2	S.D. ±	% S.D. ±	Mean Mgms. O_2	S.D. ±	% S.D. ±	Mean Mgms. O_2	S.D. ±	% S.D. ±	Mean Mgms. O_2	S.D. ±	% S.D. ±	% S.D. ±
Per liter substrate 5-day B.O.D., 128.9 to 221.7	21.8	5.26	24.1	48.7	13.7	28.2	70.3	17.8	25.3	135.7	24.4	18.0	23.9
Per 100 p.p.m. 5-day B.O.D. per liter substrate	12.9	3.05	23.6	28.8	6.4	22.2	41.1	7.8	19.0	79.8	10.5	13.1	19.5
Per gram suspended solids	15.3	6.50	42.3	33.6	13.5	40.2	48.9	21.1	43.2	97.7	55.2	56.6	45.6
Per gram volatile suspended solids	20.4	9.23	45.3	44.9	18.7	41.7	65.9	31.0	47.1	134.4	79.9	59.6	48.6
Per 100 p.p.m. 5-day substrate B.O.D. per gram suspended solids	8.6	2.98	34.7	18.9	5.1	27.0	27.2	7.7	28.3	55.1	23.5	42.7	33.1
Per 100 p.p.m. 5-day substrate B.O.D. per gram volatile suspended solids	11.0	3.62	32.9	25.0	6.5	26.0	36.5	11.3	31.0	74.1	34.3	46.3	34.1

S.D. = Standard Deviation.
% S.D. = Percentage Standard Deviation.

of oxygen used for various units of aeration mixture have been calculated. The mean number of milligrams of oxygen, the standard deviation from the mean and the percentage standard deviation for the results obtained at the ½, 1½, 3 and 24 hour aeration periods are shown in Table VI.

To determine the quantity of oxygen used to stabilize the pure culture sludge itself in these experiments, the milligrams of oxygen used to oxidize substrate as shown in Table V are subtracted from the corresponding amounts of oxygen used in the entire feed aeration mixture as shown in Table II. The milligrams of oxygen used to oxidize sludge obtained in this way are shown in Table VII.

TABLE VII.—*Milligrams of Oxygen Used to Oxidize the Pure Culture Sludge Suspension Alone*

Exp. No.	P.p.m. Sludge	Mgms. O_2 Used to Oxidize Sludge in 1.0 Liter of Mixture in Indicated Time, Hours						Mgms. O_2 Used per Gram of Sludge in Indicated Time, Hours						Mgms. O_2 Used per Gram of Volatile Solids in Indicated Time, Hours					
		½	1½	3	5	10	24	½	1½	3	5	10	24	½	1½	3	5	10	24
1	1420	6.7	7.1	10.8	15.0	—	35.0‡	4.7	5.0	7.6	10.6	—	24.6‡	6.3	6.6	10.1	14.0	—	32.6‡
2	1632	5.2	4.7	8.3	15.3	—	47.6‡	3.2	2.9	5.1	9.4	—	29.2‡	4.2	3.8	6.7	12.4	—	38.6‡
3*a*	843	9.9	11.9*	—	14.9†	—	23.6	11.7	14.1*	—	17.6†	—	28.0	16.6	20.0*	—	25.0†	—	39.6
3*b*	843	7.6	9.7*	—	15.4†	—	22.0	9.0	11.5*	—	18.2†	—	26.0	12.7	16.3*	—	25.8†	—	37.0
4	2868	5.1	9.3	12.9	31.6	34.9	47.0	1.8	3.2	4.5	11.0	12.2	16.4	2.8	5.2	7.2	17.5	19.4	26.2
5	1728	11.8	12.1	13.9	17.5	24.0	37.3	6.8	7.0	8.0	10.1	13.9	21.6	7.4	7.6	8.8	11.1	15.2	23.6
6	2544	7.9	11.4	16.9	19.0	36.3	59.7	3.1	4.5	6.6	7.5	14.2	23.4	4.9	7.1	10.5	11.9	22.7	37.4
7	1632	9.0	4.7	16.7	14.5	22.2	33.4	5.5	2.9	10.2	8.9	13.6	20.5	5.8	3.0	10.8	9.4	14.3	21.6

* Two hours. † Four hours. ‡ Twenty-two hours.

From the values in Tables VII and II, the percentages that the oxygen used to oxidize sludge are of the total oxygen used in the feed aeration mixtures have been calculated. These percentages are shown in Table VIII for all experiments. On the average about 27.3 per cent of the oxygen used in a freshly dosed pure culture sludge during the first one-half hour of aeration is required to oxidize the sludge. This

TABLE VIII.—*Percentage of the Total Oxygen Used in Fed Pure Culture Sludge Aeration Mixtures that is Required to Oxidize the Sludge Alone*

Experiment Number	Percentage of Total Oxygen Used to Oxidize the Sludge in Indicated Aeration Time in Hours					
	½	1½	3	5	10	24
1	20.6	12.6	14.0	15.0	—	23.2 ‡
2	14.0	5.5	7.0	11.0	—	22.6 ‡
3*a*	35.0	17.4 *	—	16.3 †	—	12.9
3*b*	26.7	15.0 *	—	16.9 †	—	12.0
4	19.1	18.4	17.9	37.7	31.2	30.2
5	34.0	17.4	19.2	15.4	18.3	24.2
6	38.8	22.8	21.0	18.4	26.6	27.5
7	30.0	10.2	20.0	18.2	22.8	24.1
Mean	27.3	14.9	16.5	18.6	24.7	22.1

* Two hours. † Four hours. ‡ Twenty-two hours.

percentage drops to about 15 after one and one-half hours of aeration and then apparently slowly rises approaching the original figure after 24 hours.

The cause of this rather high percentage of oxygen (27) that is used to oxidize sludge during the first one-half hour is no doubt due to a degradation of the sludge during the preparation for the experiment while the sludge is settling and is not being aerated. A plausible explanation would seem to be that prior to the start of the experiment, the sludge has had no food material added for 24 hours and during this time the easily available food material has become exhausted and a bacterial death rate has apparently set in, thus providing an increased proportion of food for the bacteria remaining, which is a contributory cause of the high oxygen consumption of the sludge during this period. During the next two to four hours, the sludge bacteria reach their maximum rates of oxidation and are apparently also reproducing at their

TABLE IX.—*Percentage of Total Oxygen Used in Pure Culture Sludge Aeration Mixtures that is Required to Oxidize Sludge*

	No. of Expts.	Mean Substrate B.O.D.	Percentage of the Total Oxygen Used to Oxidize the Sludge in Indicated Time, Hours					
		5-days	½	1½	3	5	10	24
Feed-sludge mixtures	8	172.0	27.3	14.9	16.5	18.6	24.7	22.1
Sludge-old supernatant ($x + 1.y$)	1	13.8	83.4	75.3	—	74.4	—	66.0
Sludge-old supernatant ($x + .375y + .625d$)	2	6.35	86.9	74.0	81.1	83.2	—	90.4
Sludge-old supernatant ($x + .1y + .9d$)	4	1.28	97.8	94.5	95.3	96.0	96.6	96.8

maximum rate. The smallest portion of the total oxygen is used to oxidize the pure culture sludge during this period and the percentage so used falls to about 15. After 4 or 5 hours the most easily available food supply is exhausted, the rate of reproduction of the organisms falls while the death rate with the consequent increase in degradation products slowly rises. This results in a very slow increase in the percentage of oxygen that is being used to stabilize the sludge itself during the remainder of the 24 hour aeration period.

Table IX shows the percentages of the total oxygen used in pure culture sludge aeration mixtures that are required to oxidize the sludge for substrates of varying initial B.O.D. It will be noticed that the percentage of oxygen used to oxidize the sludge alone in an aeration mixture varies inversely with the B.O.D. of the substrate. When a pure culture aeration mixture having a B.O.D. of the substrate of 6 to 14 p.p.m. in 5 days was aerated, about 86.9 to 83.4 per cent of the oxygen used was required to oxidize the sludge during the first half hour. When the supernatant of such a mixture was withdrawn and a feed material was added until the 5-day B.O.D. of the substrate was 172, the oxidation rate in the aeration mixture increased and the percentage of

TABLE X.—*Composite Oxidation Results for All Experiments*

	Mgms. O_2 Used per Liter of Fed-sludge Aeration Mixture in Indicated Time, Hours				
	½	1½	3	5	24
Oxidation of pure culture sludge	7.9	8.5	13.2	21.5	38.2
Oxidation of supernatant substrate	21.8	48.7	70.3	83.3	135.7
Total oxidation of aeration mixture	29.7	57.2	83.5	104.8	173.9

oxygen used to oxidize sludge fell to about 27.3 per cent of the total used. This illustrates that the percentage of oxygen used by the pure culture sludge in a sludge-aeration mixture varies considerably depending apparently upon the condition of the sludge itself and the B.O.D. of the substrate.

The composite oxidation results for all experiments with pure culture sludge have been calculated and are shown in Table X. These results are plotted in Fig. 4. The lower curve in this figure represents the average oxidation of the pure culture sludge alone. The intermediate curve shows the average oxidation of the substrate alone by the pure culture sludge. The upper curve represents the total oxidation in the fed aeration mixtures and each point on it includes the sum of corresponding points of the other two curves. The total oxidation curve for all substrate-sludge aeration mixtures can be separated into two components, one representing the oxidation of the sludge and the other the oxidation of the substrate. In this composite curve the oxida-

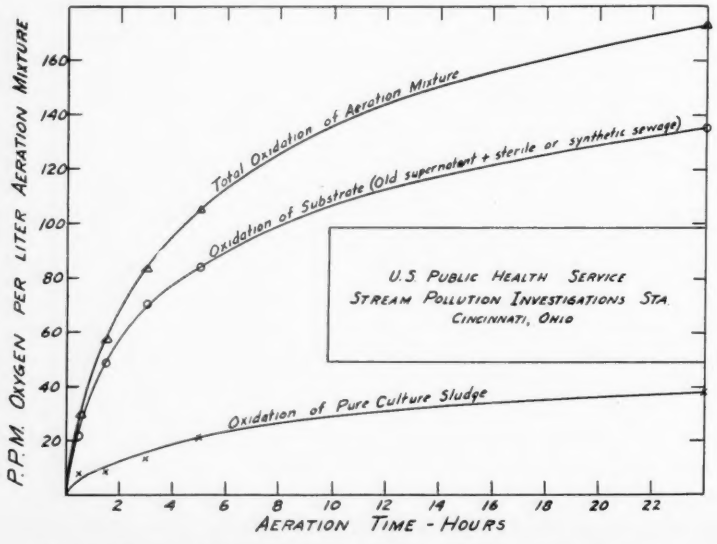

FIG. 4.—Mean oxidation curve for all pure culture sludge experiments.

tion of the sludge varies between 27 and 15 per cent of the total oxidation. As the B.O.D. of the substrate falls the substrate oxidation curve also falls and the oxidation of the sludge represents a larger proportion of the total oxidation as has already been shown in Table IX.

Substrate Oxidation Rates Effected by Pure Culture Sludges.—The expression, $Y = L - [a(10^{-K_1 t}) + b(10^{-K_2 t})]$, suggested by Theriault and McNamee,[6] was graphically fitted to the substrate oxidation results shown in Table V. In this equation the constants a and b correspond to the L_1 and L_2 portions of the total demand. In fitting this expression to these results, the total first stage demands (L values) were estimated from the 5-, 10- and 20-day dilution method B.O.D. of the substrates, corrected for oxygen used to form nitrites and nitrates. The constants thus obtained are shown in Table XI. The observed values

TABLE XI.—*Constants for Curves for Substrate Oxidation by Pure Culture Sludge*
Constants to fit the expression $Y = L - [a(10^{-K_1 t}) + b(10^{-K_2 t})]$

Exp. No.	L Estimated Total Carbonaceous Demand	a	b	t Expressed in Hours		t Expressed in Days	
				K_1	K_2	K_1	K_2
1	274 *	65	209	.313	.0057	7.51	.136
2	326 *	109	217	.357	.0054	8.57	.129
3*a*	273 †	45	228	.377	.0122	9.05	.293
3*b*	273 †	46	227	.416	.0126	9.98	.302
4	176.5 ‡	41.5	135	.526	.0126	12.6	.302
5	217.8 ‡	74.8	143	.427	.0070	10.2	.168
6	216.0 ‡	51	161	.286	.0150	6.86	.360
7	179.7 ‡	51.7	128	.377	.0095	9.05	.227

* Estimated from 5-day B.O.D. values.

† Estimated from 5 and 10-day B.O.D. values.

‡ Estimated from 5, 7, 10, 15, 20 and 35-day B.O.D. values corrected for NO_2, and NO_3 formed.

(Table V) fitted the derived curves reasonably well and the constants indicate in all cases a very high rate biochemical oxidation by these pure culture sludges. It will be noted that there is considerable variation in the constants obtained from the several experiments, *i.e.*, K_1 (the velocity constant for the rapid oxidation representing about 25 per cent of the total carbonaceous demand) varies from 68 to 126 times the single velocity constant ordinarily accepted as representative of normal biochemical oxidation as observed in diluted samples or in streams. This variation, probably, was to be expected as: (1) these sludges were developed using three different strains of bacteria, each in pure culture; (2) five sludges were developed on sterilized natural sewage and two were developed on synthetic sewage; and (3) the feed was varied so that sludge developed on natural sewage was tested with synthetic sewage feed and sludge developed on synthetic sewage was tested with natural sewage feed.

Summary and Conclusions

The literature dealing with the biochemical oxidation of sewage by activated sludge is reviewed briefly.

Various bacteria which make up a major portion of the bacterial flora of activated sludge have been isolated in pure culture. Employing these bacteria in pure culture, activated sludge has been produced in sterilized natural sewage and in sterile synthetic sewage. This production of activated sludge in synthetic sewage (which was entirely free from detritus and suspended substance) by pure cultures of bacteria is definite evidence that these bacteria, at least under the conditions of test, are responsible for the production of activated sludge.

Using a procedure which has been developed for the determination of the rate of biochemical oxidation of activated sludge mixtures it was found that the addition of fresh nutrient substrate to these pure culture activated sludges under aeration very greatly increased the quantities of oxygen utilized. The increase observed when the oxygen requirements of fed mixtures and control mixtures are compared has been attributed to the oxidation of the added substrate.

The results show that about 50 per cent of the 5-day B.O.D. of a sewage is oxidized by 5 hours aeration with these pure culture sludges and that about 80 per cent of the 5-day B.O.D. is oxidized in 24 hours. Nitrogenous materials are not included in this oxidation as these bacteria are not capable of such action. With freshly dosed sludge the oxygen required for the oxidation of the sludge alone represented from 15 to 27 per cent of the total.

The expression suggested by Theriault and McNamee was fitted to the data for the first stage, or carbonaceous oxidation of the substrate, obtained when sewage was aerated with these pure culture sludges. The results indicate that during the first 3 to 5 hours of aeration the velocity constant of the oxidation rate is 68 to 126 times greater than the established constant for normal biochemical oxidation in diluted samples or in streams. This rapid rate of oxidation "breaks" after 3 to 5 hours of aeration but the velocity constant for the remainder of the 24 hour period is still considerably greater than the established constant.

It may be concluded from the results of these tests with sludges developed by bacteria in pure culture that reactions of the same general type are indicated in each test and that the velocity constants are all much greater than the constant for normal biochemical oxidation.

While it is desired to emphasize the primary importance of bacteria in the activated sludge process of sewage purification, it is not desired to create the impression that these bacteria, whose activities are reported, are the only ones which can promote rapid oxidation under such conditions. No doubt there is a considerable group of organisms capable of such action. The primary prerequisite for this type of organism, in addition to oxidizing capacity, appears to be the ability to grow in a liquid medium in a massed floc or colony which binds itself

together tenaciously enough to remain intact under the agitation of the aeration required to maintain aerobic conditions.

It is desired to express our sincere appreciation to the members of the staff of the Stream Pollution Investigations Station of the U. S. Public Health Service for their assistance in preparing the drawings for the figures, in critically reviewing the paper, and especially to Assistant Bacteriologist Elsie Wattie for assistance in the analytical work and in the preparation of pure culture sludges.

Appendix

Technique for the Aeration Method B.O.D. Determination

Before aerating the sludge mixtures, samples of gas from each closed aeration bottle are taken. Oxygen U-tube absorption vessels are required for each test. The stopcock *A* of the absorption vessel (see Fig. 5) is turned to connect with the 2 ml. cup and with the stopper removed, distilled water of known oxygen content is siphoned into the right hand limb of the U-tube. The delivery tube of the siphon is kept near the bottom of the U-tube and water is added to fill the capillary bore leading to the 2 ml. cup. The stopcock is then turned to communicate with the capillary tube alongside the cup.

The procedure used to obtain a sample of gas consists of the following steps: (1) connect the water-jacketed gas burette with the aeration bottle; (2) the U-tube absorption vessel, filled with distilled water of known oxygen content, is connected to the gas burette; (3) the air in the capillary tube connecting the U-tube and gas burette is replaced by water drawn from the U-tube by lowering the mercury level of the burette; (4) the air and excess water are expelled from the apparatus, after turning the stopcock *B* 180°, by raising the mercury level of the burette; (5) the mercury level is allowed to rise above stopcock *C* and held in this position by closing the stopcock at the base of the burette; (6) the stopcock *C* is now turned 45° and the mercury allowed to flow back into the reservoir by opening the stopcock at the base of the burette; (7) the mercury level is now adjusted so that it is at the 10.000 ml. graduation on the stem of the burette (the stopcock at the base of the burette is used to control this manipulation); (8) the 10 ml. sample of gas is transferred to the U-tube absorption vessel by turning stopcock *B* 180° and raising the mercury reservoir, after opening the stopcock at the base of the burette; (9) close stopcock *A* after all the gas and a little mercury have entered the U-tube; (10) close stopcock *C;* (11) disconnect U-tube from burette, insert glass stopper, invert and allow the mercury to flow from U-tube by opening stopcock *A;* (12) close stopcock *A* and return U-tube to an upright position in such a manner that all the gas will be on the stopcock side of the U-tube.

With stopcock *A* closed, and with the gas in the closed limb of the U-tube, 1 ml. of each of the usual Winkler reagents is added through the open limb. The reagent pipettes are inserted to the bottom of the U-tube and care must be taken not to deliver any reagent in the upper

part of the tube. Pipettes which terminate in tubes of small bore should be used and after being filled with reagent should have their outsides flushed with running water. When the reagents have been added, the stopper is replaced and the U-tube is agitated mechanically for 10 minutes. An International shaker with a special head to accommodate 4 oxygen absorption U-tubes has proven very satisfactory for this purpose in our laboratory. With this shaker it was found that all of the oxygen could be transferred from the gas to the liquor well within the ten minute period so that this period of agitation always insured the completion of this reaction.

After the proper agitation, the acid (1 ml. of conc. H_2SO_4, sp. gr. 1.84) is added to the 2 ml. cup and allowed to run into the U-tube. After shaking to dissolve the precipitate, the liberated iodine is titrated with 0.025 M sodium thiosulphate (1 ml. of 0.025 M thiosulphate corresponds to 0.2 mgm. of O_2).

To correct for the volume of oxygenated distilled water added to the absorption vessel it is convenient to calibrate each U-tube with reference to graduated markings as shown in Fig. 5. Then before acidification,

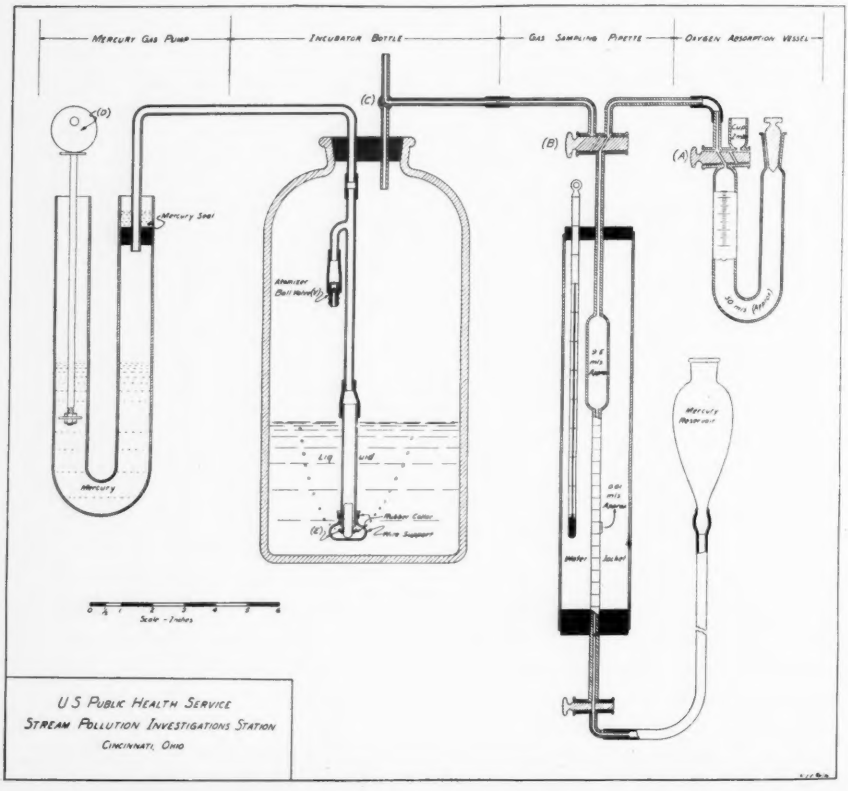

FIG. 5.—Apparatus for determining B.O.D. by the aeration method in a closed system.

TABLE XII.—*Computation-Aeration Method for Oxygen Demand of Activated Sludge Mixtures*

Date: *3–19–36.* Nature of sample: *Pure culture sludge + sterile sewage.* Series: *1.*
Total volume aeration bottle = T = 4058 mls.
Settled sludge volume 375 mls.
Dilution water or feed volume added 675 mls.
Total volume aeration mixture 1000 mls.

Time of sampling	t	t_1	t_2	t_3	etc.
Period of aeration, elapsed time, hours	0	0.5	1.5		
Volume of expanded gas = (V mls.)					
V_1 = Initial volume of gas in bottle = $T - 1000$	3058	3058	3058		
t = Volume of gas to mercury level on sample bottle limb of mercury U tube	50	47	46		
V_t = Total initial volume of gas = $T - 1000 + t$	3108	3105	3104		
v = Expanded sample of gas = 10 ml.					
V = Total volume expanded gas = $V_t + 10$ *	—	3115	3114		
Dissolved oxygen in water used in U tube (mls. titrated = 200)					
Readings with .025M Sodium Thiosulphate R	16.14				
R_1	7.32				
A = Mgm. per liter	8.82	8.82	8.82		
Gaseous oxygen, milligrams per ml. of gas (= r)					
B = Mls. of H_2O used in U tube	30.20	30.20	30.20		
v = Mls. of gas sampled = 10 ml.					
Readings with .025M Sodium Thiosulphate R	44.70	35.70	37.48		
R_1	30.45	22.00	24.20		
D = Mls. N/40 Thio. used = $R - R_1$	14.25	13.700	13.280		
f = Factor for mgm. O_2 per ml.	0.20				
fD = Mgms. O_2 in U tube	2.850	2.740	2.656		
E = Mgms. O_2 in H_2O in U tube = $AB/1000$	.266	.266	.266		
F = Mgms. O_2 in 10 mls. gas = $fD - E$	2.584	2.474	2.390		
r = Mgm. O_2 per ml. of gas = $F/V = F/10$	.2584	.2474	.2390		
Gaseous oxygen before sampling (*i.e.* including the sample) mgm. per liter of liquid					
$r \cdot V = g$	—	770.7	744.2		
Gaseous oxygen after sampling (*i.e.* excluding the sample) mgm. per liter of liquid					
$r \cdot V_t = g^1$	803.1	768.2	741.9		
Initial oxygen content, total mgms. per liter liquid = O^1					
$O^1 = g^1$	—	803.1	768.2		
Final oxygen content, total mgms. per liter of liquid = O					
$O = g$	—	770.7	744.2		
Oxygen demand over given period = (Z mgms. per liter, t to t_1) etc.					
$Z = O_1 - O$	—	32.4	24.0		
Oxygen demand, for cumulative period = $Y = \Sigma Z$ = mgms. per liter total					
$Y = \Sigma Z$	—	32.4	56.4		

* Very small volume of gas expanded in capillaries is considered negligible.

the volume of water used may be read off directly. The 2 ml. of reagents used are deducted from the total volume of liquid, on the assumption that the Winkler reagents contain no dissolved oxygen.

After each period of aeration, the aeration machine is stopped, the gas volume on the aeration limb of the mercury pump U-tube is read and the gas is sampled and analyzed as described. All readings may be recorded on a convenient form as shown in Table XII.

Table XII has been arranged to be self-explanatory and to illustrate the complete method of calculation of the oxygen consumption in milligrams per liter for the periods for which samples are collected. As 1 liter quantities of liquid mixtures are used, the figures obtained represent directly parts per million of oxygen used for the periods covered.

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THE VACUUM FILTRATION OF SLUDGE AFTER VARIOUS DIGESTION PERIODS

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Numerous experiments have been conducted in the laboratory and the field on the vacuum filtration of both raw and digested sludge from preliminary sedimentation tanks. No published data are available, however, on the relative filterability of sludge after various periods of digestion. Previous studies [1] have indicated that digested sludge gives higher cake yields than undigested material. The problem is of special interest at sewage plants where sludge is digested and then filtered. It may be more economical to dewater material that is not thoroughly digested with little or no sacrifice in filtration rates and the quantity of coagulant used. If such should be the case, less digestion space need be provided. In order to obtain some information concerning this question a group of laboratory experiments was conducted at the Baltimore sewage works. The results clearly indicate that as sludge digests its filterability, when judged by the amount of cake produced, varies considerably both before and after elutriation.

Experimental Procedure

The raw sludge used for the experiments was obtained from a mechanically cleaned preliminary sedimentation tank at the Baltimore sewage works, and was in a comparatively fresh condition. The material was collected on two different days, the first portion being obtained June 9, 1936, and the second June 16. Each batch was put into a 40-gal. sheet metal drum, which was air-tight. One hundred grams of lime was added to each drum to raise the pH value. The two containers were kept in an incubator at a temperature of 28° ± 1° C. The characteristics of the raw sludges are given in Table I.

Table I.—*Characteristics of Raw Sludges*

Test	Quantity of Sludge Used, lbs.	Volatile Matter, %	Solids, %	Amino-ammonia Nitrogen, p.p.m.	pH
I	194.0	75.9	5.9	325	7.1
II	248.6	69.9	7.2	390	6.9

At regular intervals the gas was analysed, and the volumes were measured to determine the progress of digestion, Fig. 1 shows the total amount of gas produced by each of the sludges. All gas volumes have been reduced to 0° C. at a pressure of 760 mm. of mercury.

During the experiments the sludge was filtered in the following manner. Each sample was coagulated with different quantities of

ferric chloride in order to determine how the rate of filtration varied with the quantity of chemical used. The filtering equipment consisted of a 9-cm. Buechner funnel, No. 4 grade Whatman filter paper, a filter flask, attached to a Schuette and Koerting laboratory tap aspirator, and a vacuum gauge. Each sludge sample weighed 200 grams, to which sufficient coagulant and distilled water were added to bring the weight up to 220 grams. The sludge was poured into a Buechner funnel, in which a wetted filter paper had been placed. When a vacuum was applied to the sludge, the filtrate was sucked into the flask. In a short time the sludge dried sufficiently to allow air to enter the flask. This

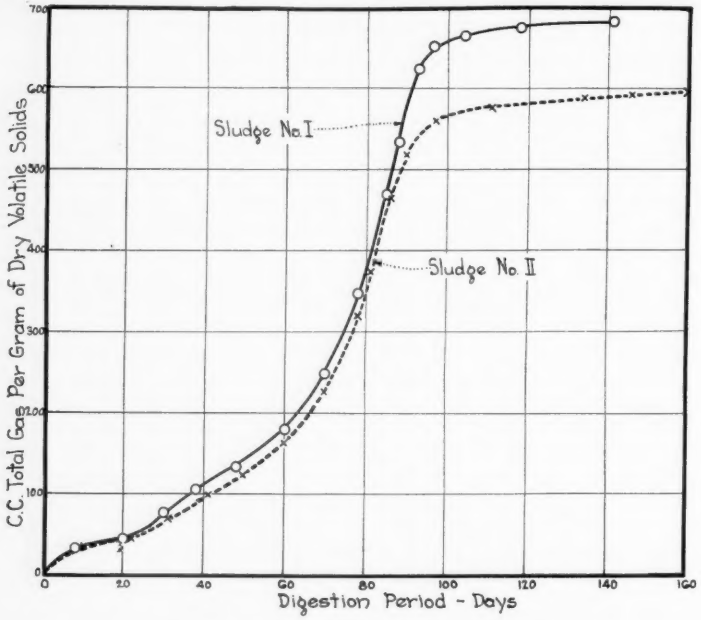

FIG. 1.—Total gas produced by raw sludge.

instant could be told by watching the vacuum gauge. The volume of the filtrate was then determined, and the filtration time was recorded. With these data the weight of dry solids filtered per minute was calculated. It is believed that these tests give a good idea of the rate of filtration that can be expected on a much larger scale in the field, as they have been confirmed when using an 18-sq. ft. vacuum filter at Baltimore. For a more detailed description of the routine followed in making tests of this type the reader is referred to an article by Genter.[2]

FILTERING ELUTRIATED SLUDGE

Samples of the sludge were removed from the two containers from time to time. Each sample was divided into two parts. One part was filtered after elutriation, and the other part was filtered without being

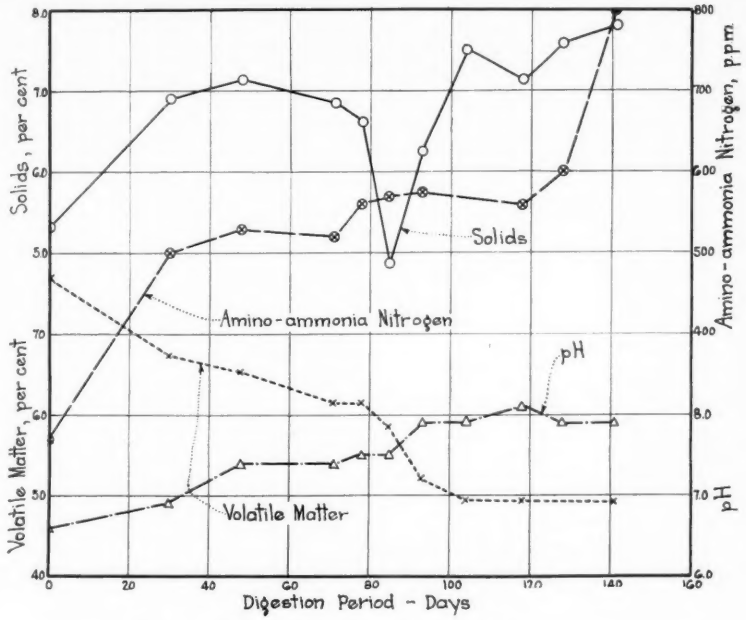

FIG. 2.—Characteristics of elutriated sludge (test I).

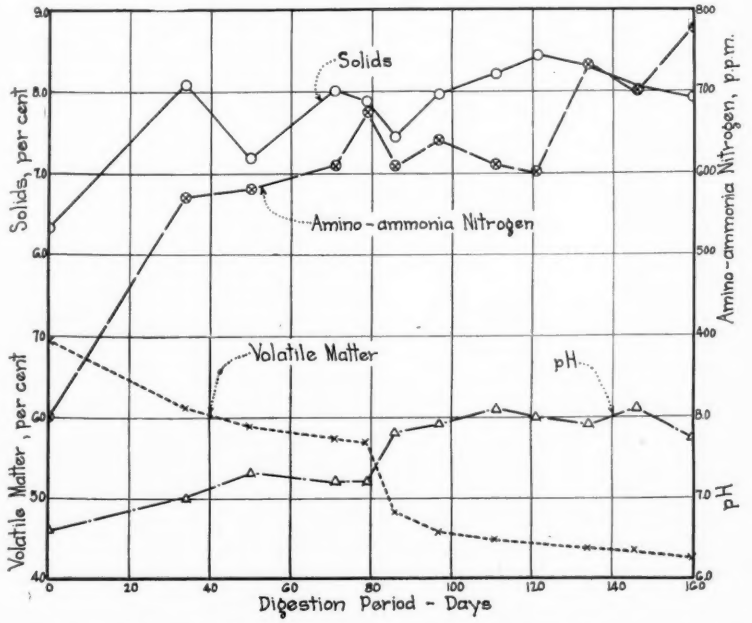

FIG. 3.—Characteristics of elutriated sludge (test II).

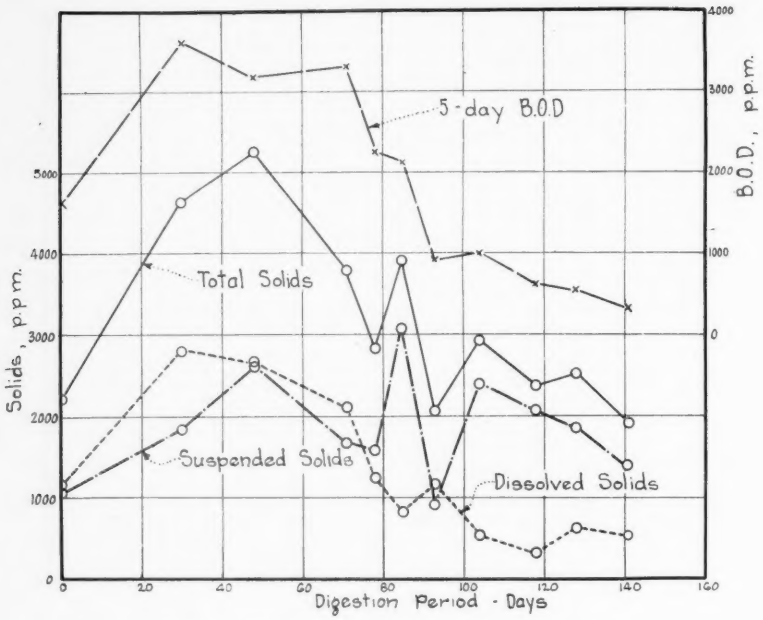

FIG. 4.—B.O.D. and solids in elutriate (test I).

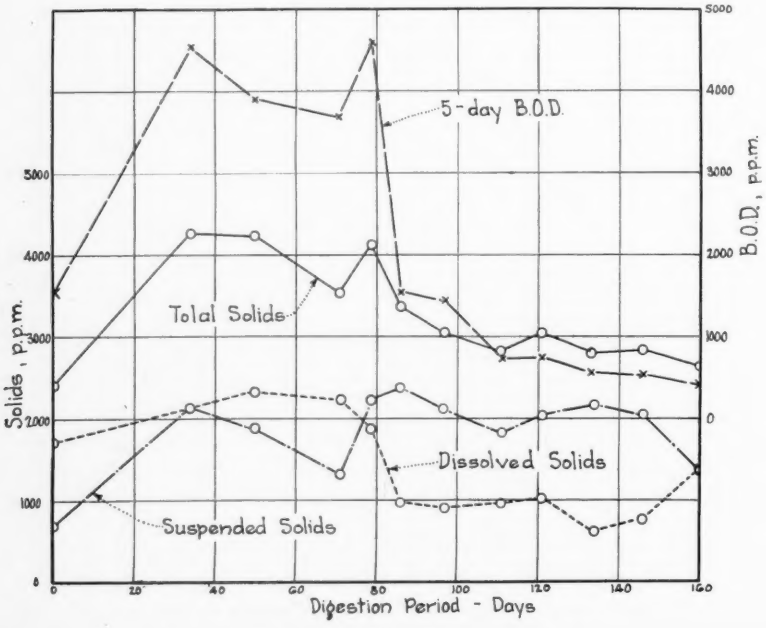

FIG. 5.—B.O.D. and solids in elutriate (test II).

elutriated. The sludge was elutriated by mixing with two volumes of tap water, and allowed to settle for 4 hours. The sludge was then drawn off and analysed. The results of these analyses are shown in Figs. 2 and 3. There was the characteristic increase in pH values and amino-ammonia nitrogen and decrease in volatile matter during the period of digestion. The 5-day B.O.D. and the solids in the elutriate are given in Figs. 4 and 5. There was a decided increase in the B.O.D. of the elutriate during the early stages of digestion. The B.O.D. remained high for about 70 or 80 days after the beginning of the tests, and then decreased to less than 500 p.p.m. The variation in the amount

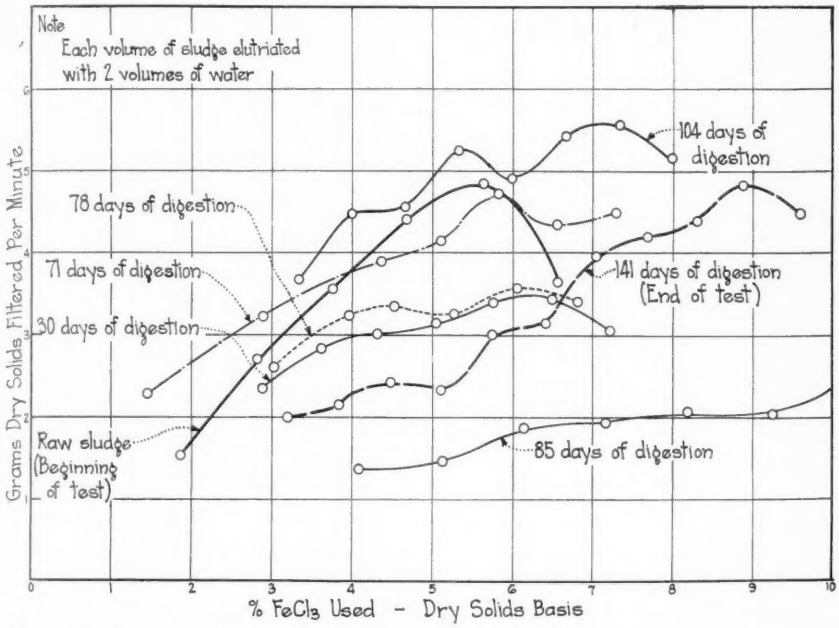
Note
Each volume of sludge elutriated with 2 volumes of water
104 days of digestion
78 days of digestion
71 days of digestion
30 days of digestion
141 days of digestion (End of test)
Raw sludge (Beginning of test)
85 days of digestion
Grams Dry Solids Filtered Per Minute
% FeCl3 Used - Dry Solids Basis

FIG. 6.—Rate of filtration of elutriated sludge after various digestion periods (test no. I).

of solids in the elutriate was somewhat similar to the change in the B.O.D.

Figs. 6 and 7 indicate how the rate of filtration varied after the sludge had been digesting for various periods of time. As was to be expected, the results were not identical when filtering the two batches of material. However, there is considerable similarity in the findings. Figs. 8 and 9 have been plotted in order to make the data more intelligible. Fig. 8, which was derived from the results obtained during Test No. 1 and shown in Fig. 6, indicates how the rate of filtration varied throughout the digestion period when the sludge was coagulated with ferric chloride in amounts equal to 4, 5 and 6 per cent of the dry solids in the sludge. In a similar way Fig. 9 has been based on the data in Fig. 7.

It is obvious that the curves shown in Fig. 8 do not entirely represent the facts. In the first place some of the curves in Fig. 6 are irregular in form. Furthermore, the ferric chloride values used in Fig. 8 in some cases intercept these curves at points which are less than and are beyond the maximum rates of filtration. In spite of these objections the curves in Fig. 8 are rather similar and are believed to indicate the general trend in the rate of filtration during the experiment. These statements relative to Figs. 6 and 8 also apply to Figs. 7 and 9.

Figure 8 shows that during the early stages of digestion the sludge used in Test I became more difficult to filter. After the thirtieth day

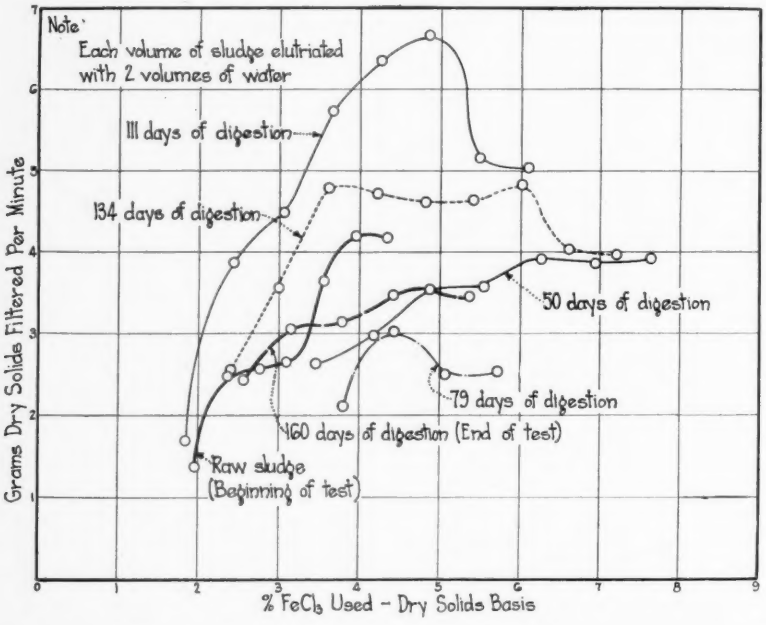

FIG. 7.—Rate of filtration of elutriated sludge after various digestion periods (test no. II).

the filtration rate increased until the seventy-first day. At this time it is estimated that the sludge was about 38 per cent digested as judged by the amount of gas produced. On the eighty-fifth day the quantity of cake produced was a minimum. Then the maximum quantity of gas was being generated. As digestion proceeded, the cake output again increased, and reached a maximum, when digestion was about complete. The material was held for about a month longer until the gas production had practically ceased. At this time the rate of filtration was again low.

The relation between the filterability of the sludge used during Test II and the length of time the sludge had been digesting is shown in Fig. 9. As digestion proceeded, the output of cake decreased and reached

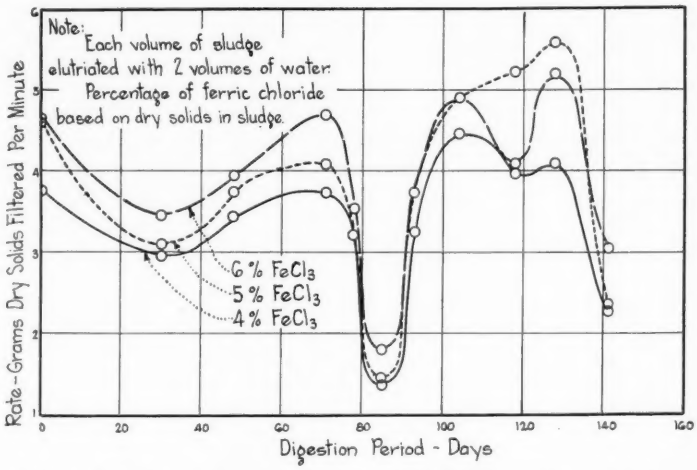
Note:
Each volume of sludge elutriated with 2 volumes of water.
Percentage of ferric chloride based on dry solids in sludge.
6 % FeCl3
5 % FeCl3
4 % FeCl3
Rate - Grams Dry Solids Filtered Per Minute
Digestion Period - Days

FIG. 8.—Rate of filtration of elutriated sludge during digestion using various quantities of coagulant—test no. I. (Compiled from data in Fig. 6.)

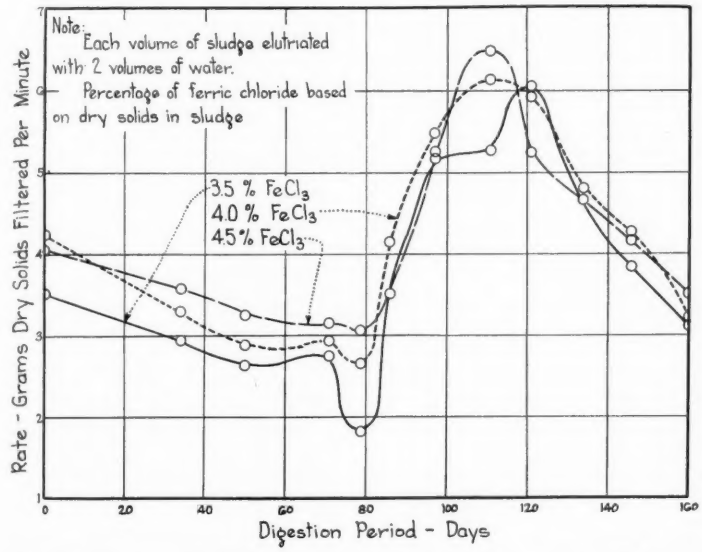
Note:
Each volume of sludge elutriated with 2 volumes of water.
Percentage of ferric chloride based on dry solids in sludge
3.5 % FeCl3
4.0 % FeCl3
4.5 % FeCl3
Rate - Grams Dry Solids Filtered Per Minute
Digestion Period - Days

FIG. 9.—Rate of filtration of elutriated sludge during digestion using various quantities of coagulant—test no. II. (Compiled from data in Fig. 7.)

a minimum on the seventy-ninth day. As in Test I, the rate of gas production at this time was quite high. From then the production of cake increased, and reached a maximum when digestion had just been completed. Holding the sludge after this period resulted in a considerable decrease in the output of cake.

Filtering Unelutriated Sludge

Tests were also made in order to determine how successfully sludge, which was not elutriated, could be filtered after various periods of digestion. As indicated in Figs. 10 and 11, much more coagulant was required to get a satisfactory cake after digestion had begun than with raw material. With the exception of the sludge removed at the end of 78 days, it was impossible to filter any of the unelutriated sludge in Test No. I until 93 days had elapsed. The unelutriated material in Test No. II was not filterable until 86 days of digestion.

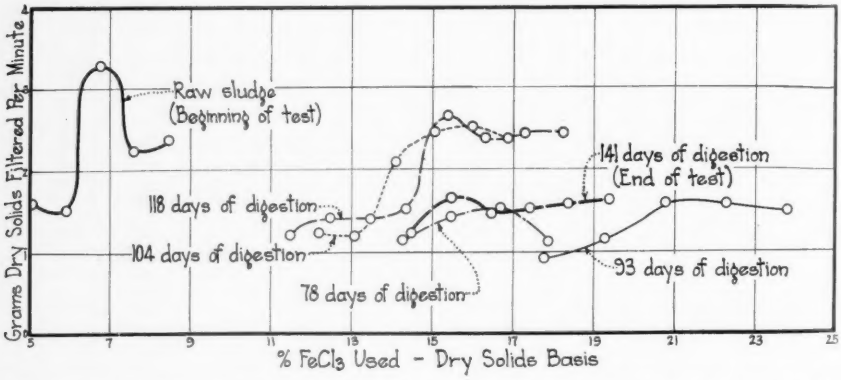
Grams Dry Solids Filtered Per Minute
Raw sludge
(Beginning of test)
118 days of digestion
104 days of digestion
78 days of digestion
141 days of digestion
(End of test)
93 days of digestion
% FeCl3 Used - Dry Solids Basis

Fig. 10.—Rate of filtration of unelutriated sludge after various digestion periods (test no. I).

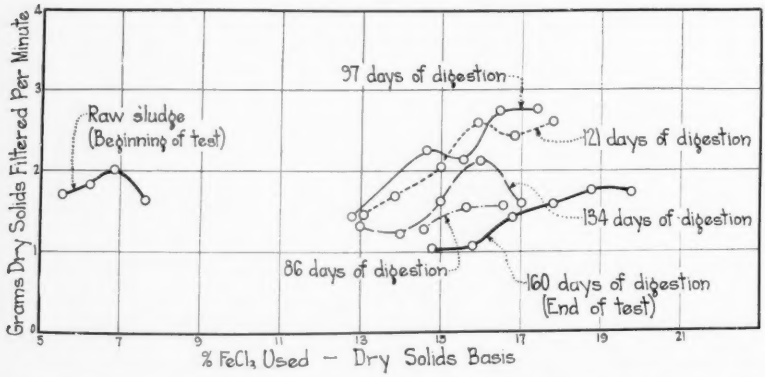
Grams Dry Solids Filtered Per Minute
97 days of digestion
Raw sludge
(Beginning of test)
121 days of digestion
134 days of digestion
86 days of digestion
160 days of digestion
(End of test)
% FeCl3 Used - Dry Solids Basis

Fig. 11.—Rate of filtration of unelutriated sludge after various digestion periods (test no. II).

Figures 12 and 13 have been derived from Figs. 10 and 11, and show how the rates of filtration vary during digestion when using various quantities of ferric chloride. Fig. 12 indicates that when digestion was at an end holding the material for a longer period resulted in lower filtration rates. This statement also applies to the results obtained during Test No. II (Fig. 13).

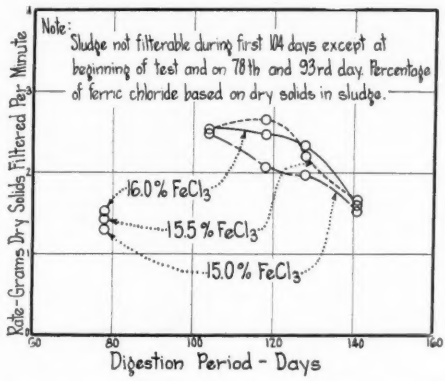
Note: Sludge not filterable during first 104 days except at beginning of test and on 78th and 93rd day. Percentage of ferric chloride based on dry solids in sludge.
16.0 % FeCl3
15.5 % FeCl3
15.0 % FeCl3
Rate - Grams Dry Solids Filtered Per Minute
Digestion Period - Days
60
80
100
120
140
160

FIG. 12.—Rate of filtration of unelutriated sludge during digestion using various quantities of coagulant—test no. I. (Compiled from data in Fig. 10.)

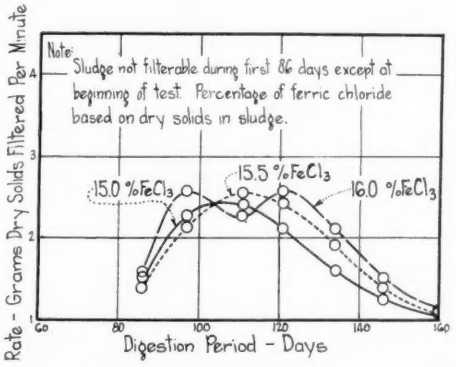

FIG. 13.—Rate of filtration of unelutriated sludge during digestion using various quantities of coagulant—test no. II. (Compiled from data in Fig. 11.)

CONCLUSIONS

The results of the two groups of experiments are not identical. There are certain similarities, however, in the findings that are of considerable interest. During both of the tests on elutriated sludge there was a short time during the digestion period when the filter rates were quite low. In each case this minimum output occurred when gasification was very active and when the sludge was from about 60 to 70 per cent digested, as judged by the amount of gas produced.

The violent gas ebullition may have caused the reduction in filtration rates. The stirring action of the gas possibly increased the amount of the colloids, and made filtration more difficult. This hypothesis was roughly checked in the laboratory by filtering sludge that had been stirred for several hours and comparing the results with the filtration of a portion of the same sludge that was not stirred. The cake output of the stirred material was much less than that of the unstirred sludge.

The tests also indicated the inadvisability of holding the material after it had digested, as the filtration rates greatly decreased. It is believed that this decrease is partly the result of an increase in amino-ammonia nitrogen, which requires the use of large quantities of coagulant. It should be pointed out that the experiments were naturally limited in scope, and the results should not be considered as having a general application until further tests have been conducted at other sewage plants.

The Baltimore sewage works is under the general supervision of B. L. Crozier, chief engineer, Department of Public Works, and G. E. Finck, sewerage engineer with G. K. Armeling, superintendent. J. W. Bushman, junior chemist, assisted in the laboratory work.

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1. C. E. Keefer and Herman Kratz, Jr., "The Vacuum Filtration of Elutriated Sludge," *This Journal*, **6**, 845 (1934).
2. A. L. Genter, "Adsorption and Flocculation as Applied to Sewage Sludges," *This Journal*, **6**, 689 (1934).

STUDIES WITH ACTIVATED CARBON IN SEWAGE SLUDGE DIGESTION *

By C. L. Walker

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The studies forming the basis of this paper were carried out in the sanitary engineering laboratory of Cornell University at the Ithaca sewage plant. From Jan. 23 to August 15, 1935 and from May 16 to Dec. 21, 1936, experimental units were under observation. Observations at the Ithaca digestion tank were made between Nov. 9, 1935 and April 12, 1936.

Acknowledgment is made to Mr. Albert N. Huff, a graduate student at the time, for initiating the studies and conducting all of the work up to July 4, 1935; to Mr. N. Statham of the Industrial Chemical Sales Company for the supply of carbon used and for suggestions during the progress of the investigation; to Mr. Woodford, Superintendent of Sewers for permission to use the Ithaca digestion tank; to Messrs. Kerr, Wormley and Ryerson, operators at the Ithaca sewage treatment plant, for the collection of samples throughout the entire period of study; and to Prof. W. L. Malcolm who carried on the work from May to September, 1936.

Initial Experimental Results

The initial experiments were carried out in the Sanitary Engineering Laboratory of Cornell University.

Three batteries each of five one-gallon bottles were used. Two of these batteries are shown in Fig. 1. Each bottle was fitted with a stopper providing means for introducing and withdrawing sludge and supernatant, and for conveying gas as formed to inverted graduated cylinders having their open ends immersed in a water bath. Each battery of five bottles was placed in a galvanized tank and surrounded by a water bath. One battery was maintained at a temperature of 20° C., the water being warmed or cooled when and as required. The other two batteries were maintained at temperatures of 28° C. and 45° C., respectively, by thermostatically controlled electrical heating units. The expansion and contraction of ether-filled wafers submerged in the water bath provided the means of breaking and making the current connection to the heating unit used. The heating unit in the case of the 28° battery was a submerged glass-enclosed electric light bulb; in the case of the 45° battery it was a filament resting on asbestos and placed beneath the galvanized tank.

Initially, on June 21, 1935, each bottle received 3 liters of digested sludge from the Ithaca plant and thereafter 100 ml. of fresh sludge

* Presented before the Ninth Annual Meeting of the New York State Sewage Works Association, New York City, January 22, 1937.

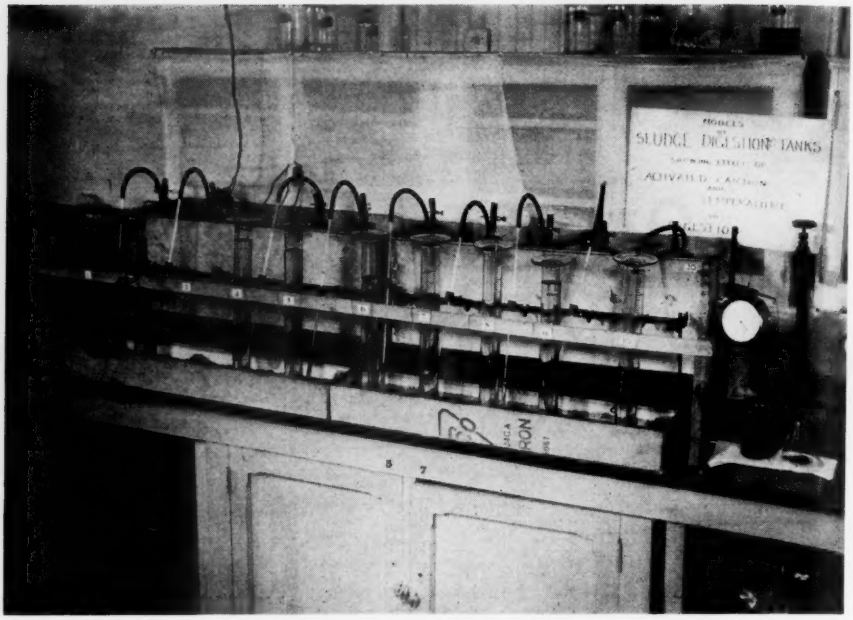

FIG. 1.—20° and 28° C. experimental digesters.

were added on each of 39 days during the 53 days duration of the test. On 9 of the 14 days when no sludge was added, sewage was being by-passed around the Ithaca plant because of the flood of July 8, and no sludge was available for experimental purposes.

The following table gives the loadings of carbon to each of the fifteen units:

Digester Number	Temperature Digestion Deg. C.	Grams of Carbon Added Daily	Equivalent to p.p.m. of Carbon in Raw Sewage
1	28	0	0
2	28	0.25	7
3	28	0.5	15
4	28	1.0	30
5	28	1.5	44
6	20	0	0
7	20	0.25	7
8	20	0.5	15
9	20	1.0	30
10	20	1.5	44
11	45	0	0
12	45	0.25	7
13	45	0.5	15
14	45	1.0	30
15	45	1.5	44

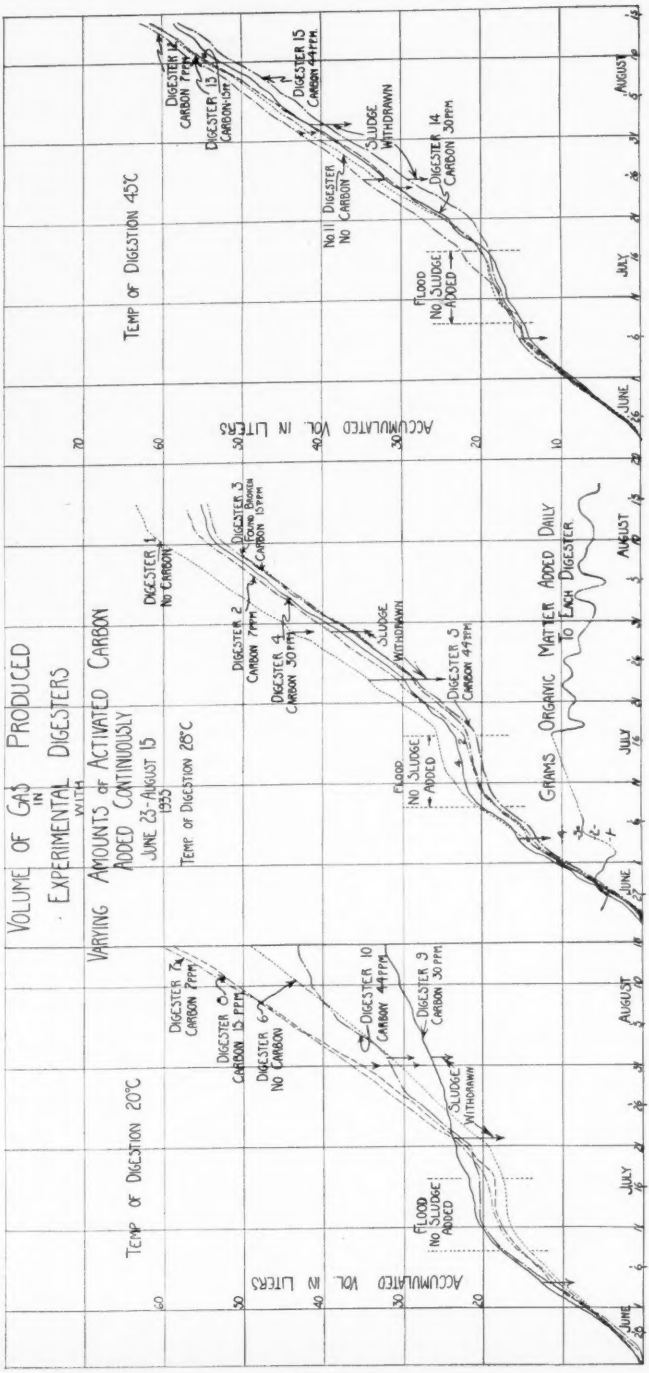
VOLUME OF GAS PRODUCED IN EXPERIMENTAL DIGESTERS WITH VARYING AMOUNTS OF ACTIVATED CARBON ADDED CONTINUOUSLY JUNE 23-AUGUST 15 1935
TEMP OF DIGESTION 20°C
TEMP OF DIGESTION 28°C
TEMP OF DIGESTION 45°C
ACCUMULATED VOL. IN LITERS
GRAMS ORGANIC MATTER ADDED DAILY TO EACH DIGESTER
DIGESTER 1 NO CARBON
DIGESTER 2 CARBON 7PPM
DIGESTER 3 CARBON 15PPM
DIGESTER 4 CARBON 30PPM
DIGESTER 5 CARBON 44PPM
DIGESTER 6 NO CARBON
DIGESTER 7A CARBON 2PPM
DIGESTER 8 CARBON 15 PPM
DIGESTER 9 CARBON 30 PPM
DIGESTER 10 CARBON 44PPM
DIGESTER 11 NO CARBON
DIGESTER 12 CARBON 7PPM
DIGESTER 13 CARBON 15PPM
DIGESTER 14 CARBON 30PPM
DIGESTER 15 CARBON 44PPM
SLUDGE WITHDRAWN
FLOOD NO SLUDGE ADDED
JUNE
JULY
AUGUST

FIG. 2.

Volume of Gas Produced

Gas was collected in inverted cylinders and withdrawn at frequent intervals, observations being made of the volume of gas, the existing temperature and barometric pressure, and the water pressure on the gas. The observed volumes of gas, reduced to the equivalent volumes at a standard temperature of 0° C. and a standard pressure of 760 mm., were used for comparative purposes. The total volumes of gas produced between June 21 and August 15 (1935) are shown in the diagrams in Fig. 2.

The average volume of gas produced in all units of a series increased with the temperature of digestion.

The drop in gas production in all units, whether receiving or not receiving carbon during the July flood period, was pronounced but the drop was of lesser magnitude at 45° than at 28° or at 20° C.

The accumulated gas volume for the sludge digested at 20° C. suggested that from 7 to 15 p.p.m. of carbon gave better gas production than no carbon. In digesters 9 and 10 gas production began to decrease after the enforced lack of feeding following the July flood. Except for digester 9 the volume of gas produced decreased with increasing carbon content.

The accumulated gas volumes for the sludge digested at 28° C. seem to indicate that digestion proceeded best without the addition of carbon, and except for digester number 3 the volumes of gas produced decreased with increasing carbon content. Up to the time of the breaking of digester number 3, only 3 per cent difference existed in the content of gas produced in the four units receiving carbon, and the amount of gas produced in each unit did not vary much after July 21.

The accumulated gas volumes for the sludge digested at 45° C. indicated slightly more gas production when 7 p.p.m. of carbon was added than for any of the other units. Without exception, the volume of gas produced decreased with increasing carbon content. Digester number 11, which received no carbon, produced the same amount of gas as was produced in digester number 13, which received 15 p.p.m. of carbon, and but 2 per cent less than that produced in digester number 12, which received 7 p.p.m. carbon.

At 20° C. carbon seemed to favor digestion materially, at 45° slightly, and at 28° it did not appear to be advantageous.

Composition of Gas

Because of the difficulty of sampling and measuring the small volume of gas produced in the units, only a few analyses of the gas were attempted. The following tests were made:

Date	Digester Number	Temp.	Composition of Gas Per Cent			
			CO_2	CH_4	H_2	Other
July 1, 1935	1	28	34.8	49.1	8.4	7.7
"	2	28	32.6	54.1	4.7	8.6
"	3	28	32.1	57.3	5.4	5.2
"	4	28	32.1	55.0	6.5	6.4
"	5	28	32.8	54.7	4.7	7.8
July 2, 1935	6	20	35.8	56.3	0.5	7.4
"	7	20	32.2	62.8	0.0	5.0
"	8	20	28.1	52.2	0.0	19.7
"	9	20	35.4	55.5	2.1	7.3
"	10	20	31.1	63.0	0.0	5.9

Drainability

The relative drainability of sludges from the fifteen units was determined by use of Buchner funnels, the filtration being continued until the mat in the funnel maintained a vacuum of 23 inches of mercury. At this vacuum the moisture content of the mat was in the neighborhood of 55 to 60 per cent.

In five of the six series of five tests each that were made, the sludge that drained most readily contained 1 per cent of carbon. The results are shown graphically in Fig. 3. Irregularities in some points in the

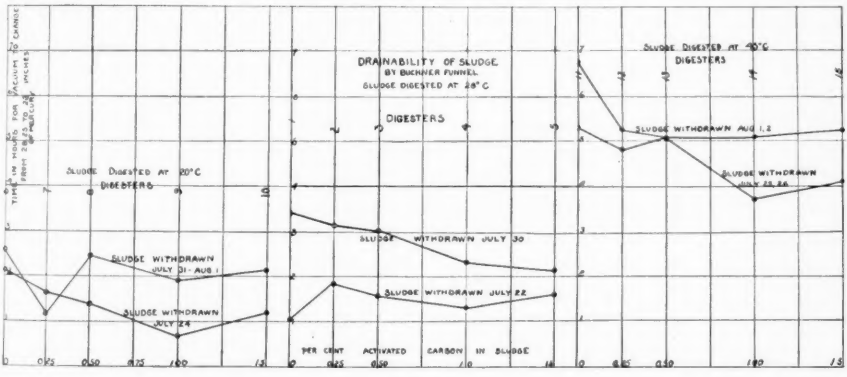

Fig. 3.

curves are due to difference in the total solids of the sludges as withdrawn. In general the presence of carbon favored more rapid draining of the sludge. Increase in the temperature of digestion increased the time necessary for draining a sludge of a given carbon content.

Sludge Characteristics

The sludge used in seeding the digesters originally contained 7.33 per cent solids of which 53.7 per cent was volatile material.

The fresh sludge added in the daily feedings contained an average of 3.5 per cent solids, varying from 1.7 to 4.5 per cent and the volatile content of the solids averaged 71.5 per cent, varying from 66 to 77 per cent. The hydrogen ion concentration ranged from 5.3 to 6.1.

The sludge drawn from the digesters during the progress of the experiments varied but little in total solids and volatile solids as is shown in the following table:

Digester Number	Total Solids, Per Cent			Volatile Solids, Per Cent		
	Max.	Min.	Aver.	Max.	Min.	Aver.
1	9.2	2.5	5.0	54.0	49.8	52.0
2	6.8	4.2	5.6	52.7	49.2	51.1
3	6.6	3.9	5.5	54.8	53.1	54.2*
4	10.0	3.1	6.0	56.9	46.1	52.8
5	5.5	2.3	4.2	58.4	41.6	52.4
6	4.7	2.3	3.8	56.3	50.3	52.4
7	9.8	2.4	5.1	56.9	48.2	52.4
8	6.8	2.7	4.5	57.0	46.3	51.3
9	9.6	3.1	5.2	56.3	48.6	53.4
10	5.9	3.5	5.0	58.7	37.5	51.5
11	4.4	1.7	3.1	54.5	48.8	51.4
12	5.7	3.6	4.5	55.6	47.4	51.6
13	5.1	2.1	3.5	55.5	47.6	51.6
14	5.2	2.4	3.5	56.7	47.2	53.5
15	4.8	1.1	3.5	60.3	44.7	54.1

* Digester number 3 broke during experiments.

Sludge was not withdrawn from the experimental digesters on August 15, 1935 when the addition of fresh sludge was discontinued. Digestion was allowed to continue until no further gas was given off. Gas production in digesters 5, 6, 7, 8, 9, 10 and 14 ceased during August, September and November, 1935. Gas continued to evolve from digesters 1, 2, 4, 11, 12, 13 and 15 until April, 1936, a period of eight months after the final fresh sludge was added. These latter digesters were operated at temperatures of 28° and 45° C. All digesters were initially charged on June 21, 1935.

Evolution of gas at 20° C. ceased prior to the time at which gas was given off at 28° and 45° C., and at 20° and 28° C. the digesters with the maximum amount of carbon were the first to cease evolving gas.

Experience at the City of Ithaca Digestion Tank

Gas Production

About the middle of November, 1935, carbon was added to the digestion tank of the City of Ithaca, the object being to observe what changes occurred when using carbon in an operating tank.

Samples of the sludge, added daily, were analyzed for total solids, ash, and for hydrogen-ion concentration; gas as produced on various

days throughout the period of operation was collected at hourly intervals for a period of 24 hours, and analyzed for carbon dioxide, methane, hydrogen, and oxygen; and the amount of gas produced each day during the period of test was obtained from meter readings. The average of the 24 or 25 samples collected on any one day was taken as the average analysis of the gas for the day.

Carbon was added to the digester in a suspension by mixing 35 pounds of the carbon with approximately 35 gallons of water and introducing the suspension into the fresh sludge entering the well from the sedimentation tank. Mixing of the carbon with the sludge was secured by the agitation of the inflowing sludge and by the pump in elevating the raw sludge to the digestion chamber. The following amount of carbon was added:

Nov. 18–Dec. 4, 1935	49 bags	1715 pounds
Dec. 10–Dec. 20, 1935	11 bags	395 pounds
Feb. 25–Mar. 17, 1936	17 bags	595 pounds
Total		2705 pounds

The rate of application varied from 5 p.p.m. to 0.6 p.p.m., except for the first day, when the carbon was applied at the rate of 8.75 p.p.m.

Figure 4 graphically shows the amount of gas produced daily; the pounds of dry volatile solids added daily to the digestion tank; the volatile matter in the fresh sludge and the hydrogen-ion concentration of the same; the days during which carbon was added to the digester; the influence of carbon on digester temperature between February 24 and March 17, 1936; and the effect of the March, 1936, flood on the amount of volatile solids added to the digester and the volume of gas produced by the digester.

On each occasion after beginning to apply carbon, gas production fell off, and since the gas generated at the plant is used for heating the pumping station as well as for heating the sludge in the digestion tank, it was deemed best to discontinue the addition of carbon even though the tank had not yet been thoroughly charged with carbon equivalent to a dose of 5 p.p.m. of incoming sewage.

While the graphs for volatile solids added to the digester, and for the volume of gas produced show some corresponding increases and decreases of volume, the two graphs do not parallel one another.

Temperature of the sludge in the digestion tank, withdrawals of sludge from the tank, and the amount of volatile solids added to the tank all influence the volume of gas produced. The relatively short intervals during which the carbon was added do not warrant attributing the decreased gas production to the addition of the carbon.

Gas Characteristics

Gas was collected at the plant on twelve days during the observation period. A summary of the analyses obtained on seven days preceding the addition of carbon, and on the twelve days following the first addition of carbon is given in the following table.

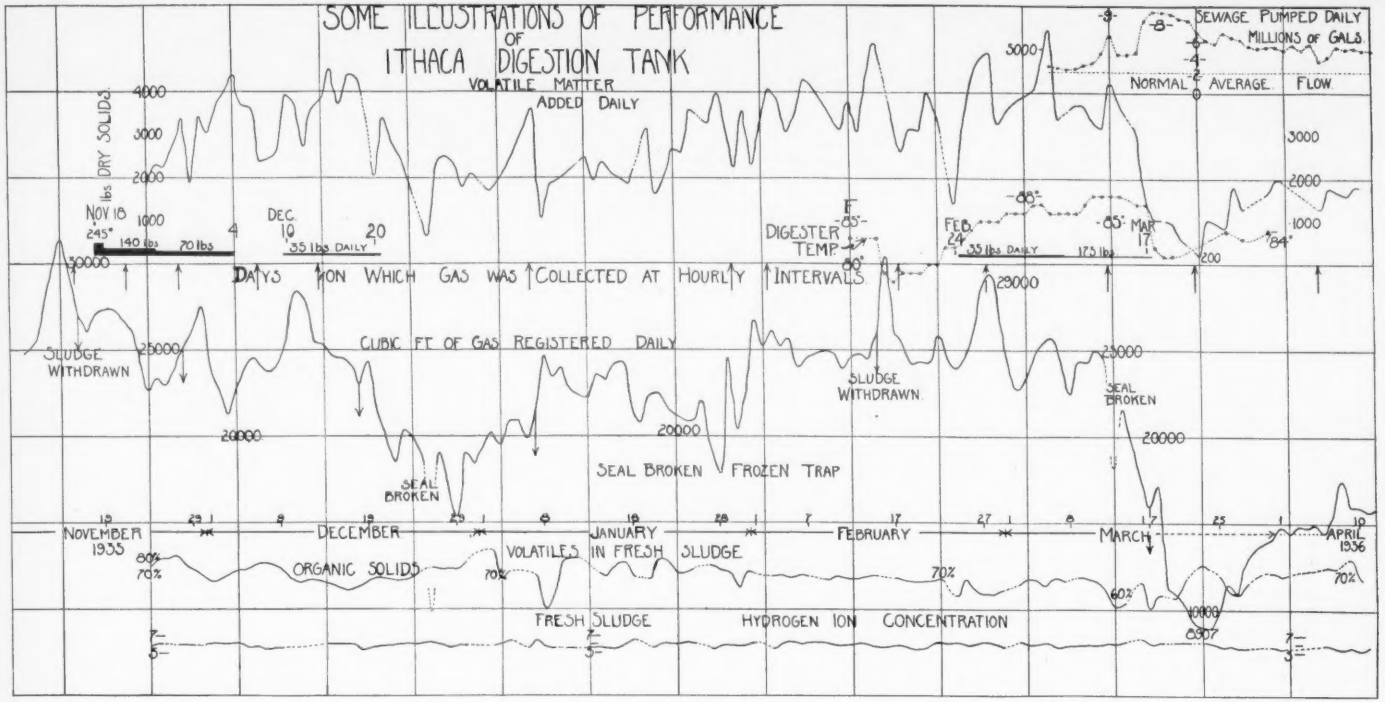
SOME ILLUSTRATIONS OF PERFORMANCE
OF
ITHACA DIGESTION TANK
VOLATILE MATTER
ADDED DAILY
lbs DRY SOLIDS
SEWAGE PUMPED DAILY
MILLIONS OF GALS.
NORMAL AVERAGE FLOW
NOV 18
245°
140 lbs
70 lbs
DEC.
10
35 lbs DAILY
20
DIGESTER
TEMP.
FEB.
24
35 lbs DAILY
175 lbs
MAR
17
DAYS ON WHICH GAS WAS COLLECTED AT HOURLY INTERVALS
CUBIC FT OF GAS REGISTERED DAILY
SLUDGE
WITHDRAWN
SEAL
BROKEN
SEAL BROKEN FROZEN TRAP
SLUDGE
WITHDRAWN
SEAL
BROKEN
NOVEMBER
1935
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
1936
ORGANIC SOLIDS
VOLATILES IN FRESH SLUDGE
FRESH SLUDGE
HYDROGEN ION CONCENTRATION
6307

FIG. 4.

Because of the variation in the composition of the gas from hour to hour, it was deemed necessary to collect hourly samples, and the average of the hourly samples was considered as giving the composition of the gas for the day.

Summary Daily Gas Analyses, Ithaca Digestion Tank

Date 1935	CO_2	CH_4	H_2	O_2	CO	Misc.	No. Samples Averaged
Sep. 11 and 12	29.6	48.2	6.8	0.7	0.2	14.5	25
14 and 15	32.8	43.4	8.3	0.8	0.2	14.5	24
19 and 20	32.7	49.7	6.7	0.4	0.3	10.2	24
20 and 21	31.8	55.4	4.9	0.5	0.1	7.3	24
Oct. 17 and 18	31.4	48.6	12.4	0.6		7.0	22
Nov. 1 and 2	33.0	43.5	8.1	0.4		15.0	24
15 and 16	32.4	43.7	6.5	0.6		16.8	24
Averages	32.0	47.5	7.7	0.6	0.2	12.0	
Added Carbon, Nov. 18–Dec. 4, Dec. 10–20, 1935							
Nov. 21 and 22	32.7	49.1	11.5	1.1		5.6	25
27 and 28	34.2	45.8	13.2	0.6		6.2	25
Dec. 6 and 7	31.3	49.9	8.4	0.6		9.8	17
Dec. 13 and 14	32.3	48.7	4.7	0.4		13.9	23
Averages	32.6	48.4	9.7	0.7		8.6	
1936							
Jan. 6 and 7	32.1	52.0	3.6	0.5		11.8	25
29 and 30	34.3	48.0	4.8	0.2		12.7	24
Feb. 2 and 3	33.6	50.1	4.5	0.2		11.6	22
17 and 18	33.6	48.5	4.5	0.2		13.1	24
Averages	33.4	49.8	4.3	0.3		12.2	
Added Carbon, Feb. 24–Mar. 17, 1936							
Feb. 27 and 28	33.9	53.7	1.4	0.2		10.8	25
Mar. 12 and 13	33.9	51.4	2.1	0.2		12.4	25
Averages	33.9	52.5	1.8	0.2		11.6	
Mar. 22 and 23	35.6	46.4	9.2	0.2		8.6	19
April 5 and 6	36.3	49.1	4.5	0.2		9.9	25
Averages	36.0	47.8	6.9	0.2			

The average values of the analyses show a slight increase in the amount of carbon dioxide, and increase of about 5 per cent in the methane content (10 per cent of the methane) and a pronounced decrease in the hydrogen content. The sum of the methane and hydrogen, however, remained fairly constant. The carbon dioxide content does not show the same variation as the hydrogen and methane, and should not be used to show the quality of the gas.

The hourly variation in the composition of the gas from the Ithaca digestion tank on three days is shown in Fig. 5.

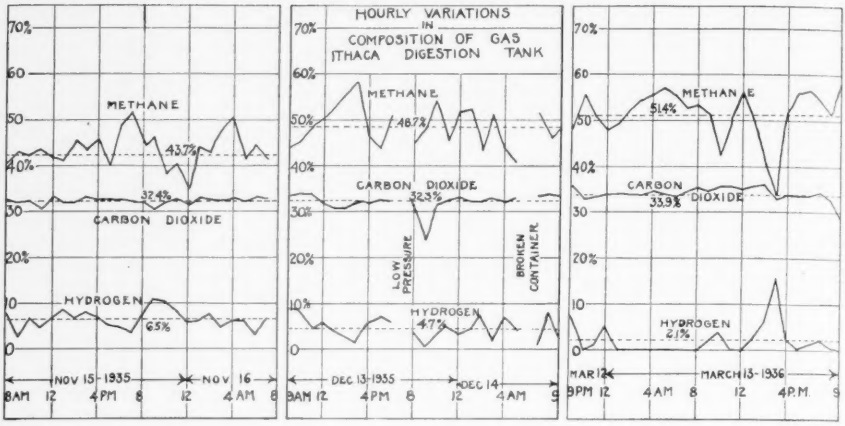

FIG. 5.

SLUDGE CHARACTERISTICS

Carbon was not added sufficiently to note changes in the sludge as withdrawn. The fresh sludge as added had a total solids content of 3.5 per cent, of which about 70 per cent was volatile, and the pH averaged slightly less than 6.0. The digested sludge as drawn from the tank on seven occasions during the observations was uniform in character having an average total solids content of 8.3 per cent, a volatile solids content of 50.7 and a hydrogen ion concentration of 7.0.

EFFECT OF CARBON ON THE TEMPERATURE OF THE SLUDGE WHEN ADDED TO THE DIGESTION TANK

From February 22 to March 17, 1936, daily observations of the temperature of the sludge in the Ithaca digestion tank were taken. Carbon was added daily from February 25 to March 17. For the first twelve days carbon was added at the rate of 1.25 p.p.m. and for ten days the rate was 0.6 p.p.m. The temperature rose from 82°F. to 88° F. during the time the carbon was being added.

A comparison of the outside air temperature curve with the temperature curve of the sludge as shown in Fig. 6 would suggest that the sludge temperature may have been influenced by external temperatures. The Ithaca digestion tank is covered with soil and it is not believed that outside temperature changes would entirely account for the rise in temperature. Sludge withdrawals account for the pronounced fall in temperature, but the increase in temperature from the average of 84° to 88° F. is believed to be due to the presence of the carbon.

EFFECT OF THE MARCH FLOOD ON THE PRODUCTION OF GAS

The March flood of 1936 exerted a marked influence on the gas production of the Ithaca digestion tank, as is shown in Fig. 4. The aver-

age flow of sewage for the year 1936 was 2,400,000 gallons daily, and on March 8 and 9 stood at that figure. For a period of twenty days following the flood the daily flow exceeded 5,000,000 gallons and on three of these days was slightly in excess of 9,000,000 gallons.

The heavy infiltration overtaxed the capacity of the two sedimentation tanks and the high velocity at which the water passed through the tanks caused diminution of settled solids to such an extent that the amount of volatile solids dropped from 3800 pounds daily to 200 pounds. The daily gas production dropped from 24,000 cubic feet to 8900 cubic feet.

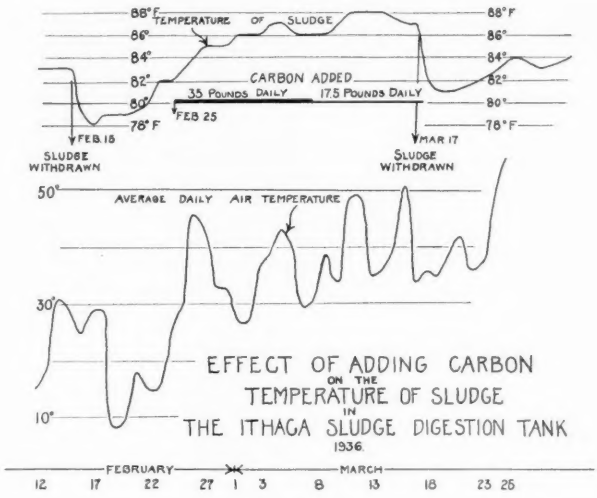

FIG. 6.

EXPERIENCE WITH LARGE EXPERIMENTAL DIGESTERS

Volume of Gas Produced

Plans having been made to begin studies in April, 1936, involving the digestion of garbage with sewage sludge, it was not possible to continue the studies with carbon at the Ithaca plant after the March flood. Carbon appearing in the supernatant overflow, and mixed with the incoming raw sewage darkened the fresh sludge and would have introduced another variable into the work with garbage.

For further investigation four experimental digesters of a battery of sixteen, as shown in Figs. 7 and 8, each of a capacity of fifty-five gallons were seeded with 30 gallons of digested sludge from the Ithaca digestion tank. To each of these there was added daily 6.75 pounds of fresh sludge. The ratio of sludge added to the experimental digester to the average sludge content of the unit was made to equal the ratio of sludge added to the Ithaca digestion tank to the sludge content of the tank.

It was not until May 15, 1936, that gas leakage from the tanks seemed to be stopped and the tanks were operated from May 15 to July 16, adding raw sludge only. At this time all of the tanks seemed to be producing gas at the same rate, although the total amount of gas produced by each digester was not the same. From July 16 to November 2, 1936, 5.34 grams of carbon was added daily, six days per week to digesters 1 and 6 with the regular charge of fresh sludge. This dosage was equivalent to between 4 and 5 p.p.m. of carbon to the sewage equivalent of the sludge. Digesters 4 and 5 received only the charge of fresh sludge. From November 2 to December 21 all four digesters

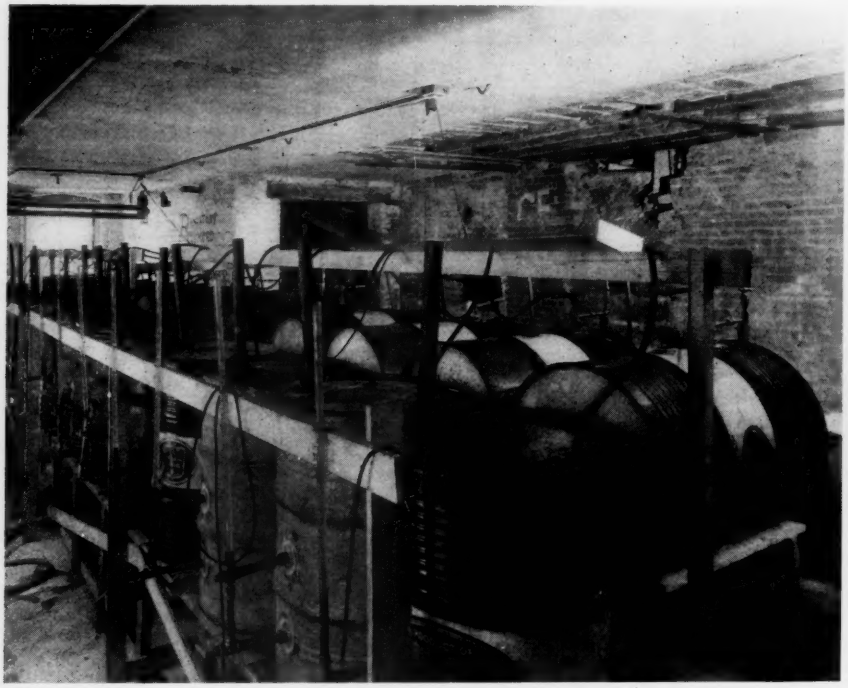

FIG. 7.—55-gallon experimental digestion tanks.

were charged with fresh sludge only. It was felt that by operating the tanks in this manner the effect on the quantity of gas produced, of adding and withdrawing carbon, would be more evident.

For a week prior to the addition of carbon to digester 6 it was producing gas at the same rate as were the other digesters. Soon thereafter and for the balance of the test period this digester showed less gas production than any of the others, suggesting the possibility of leakage. Filling all seams and covering joints did not seem to make any change in the amount of gas collected.

After sludge was withdrawn from the digesters on Dec. 21 they were all tested for leakage of air by a back pressure on air trapped in the

tanks. Considerable leakage from digester 6 was disclosed, and the observations for quantity of gas produced by the digesters are unreliable. Leakage occurred at a joint between the feed pipe and a bushing within the digester.

Slight leakage from digesters 1, 4 and 5, amounting to 1 per cent under maximum pressure possible for 24 hours was also found, the leakage from digesters 4 and 5 being a trifle in excess of that from digester 1.

The total amount of gas produced in digesters 1, 4 and 5, was 315, 318, and 333 cubic feet.

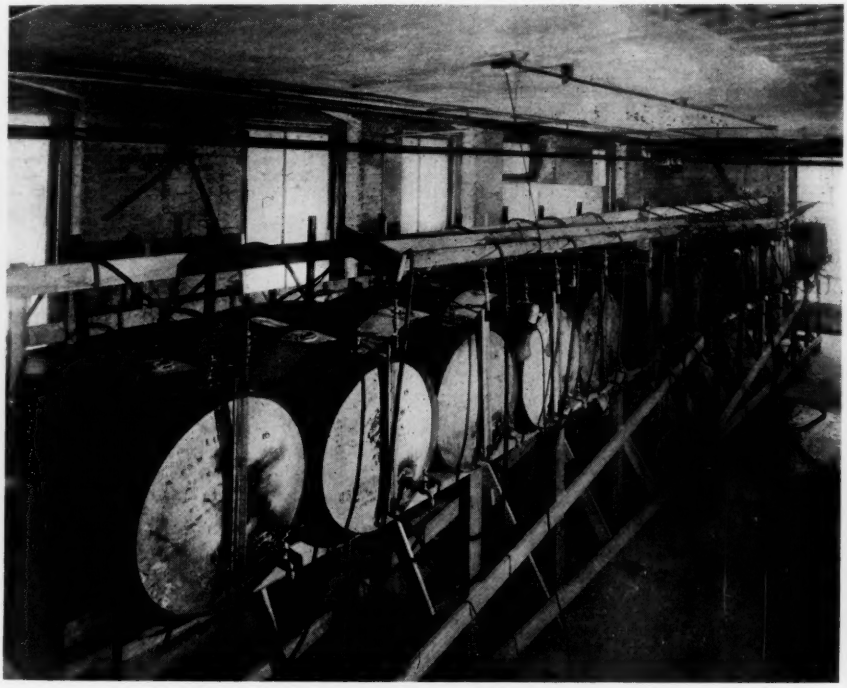

FIG. 8.—Gas collecting tanks.

The graphs as shown in Fig. 9 do not indicate any change in the rate or amount of gas production during the progress of the test in any of the digesters, of which number 1 received carbon at the rate of 4 to 5 p.p.m. of sewage flow.

Gas Analyses

Averages of analyses of the gas from each of the digesters showed very much the same trend. Little change in the amount of any of the constituents of the gas was found, though individual samples showed more pronounced variations in the amount of methane and hydrogen.

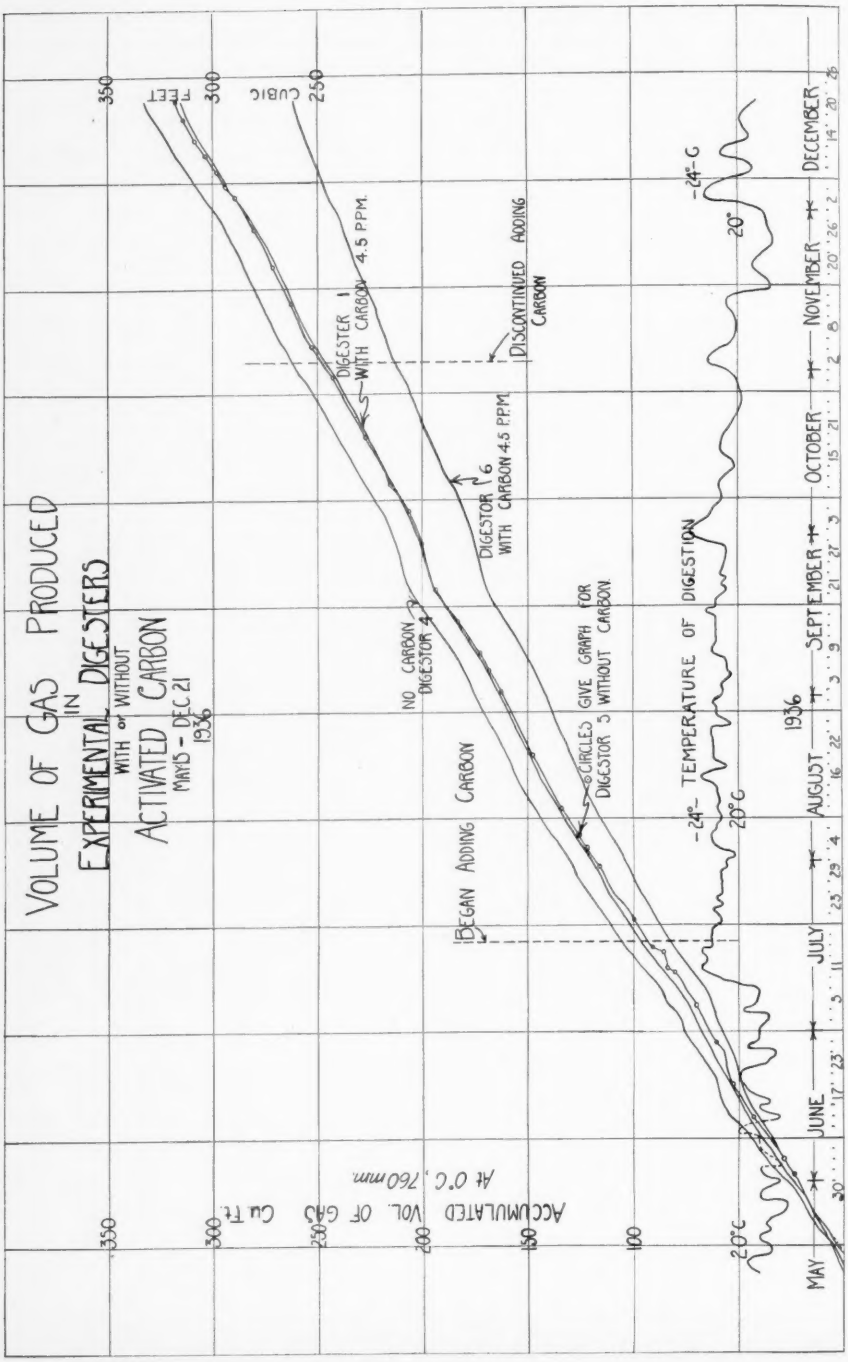
VOLUME OF GAS PRODUCED IN EXPERIMENTAL DIGESTERS WITH or WITHOUT ACTIVATED CARBON
MAY 15 - DEC 21 1936
ACCUMULATED VOL. OF GAS Cu Ft. At 0°C, 760 mm.
CUBIC FEET
DIGESTER 1 WITH CARBON 4.5 PPM.
DISCONTINUED ADDING CARBON
DIGESTOR 6 WITH CARBON 4.5 PPM.
NO CARBON DIGESTOR 4
BEGAN ADDING CARBON
CIRCLES GIVE GRAPH FOR DIGESTOR 3 WITHOUT CARBON
TEMPERATURE OF DIGESTION
MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER
1936

FIG. 9.

A summary of the averages of gas analyses is given in the following tabulation.

Period of Production 1936	Number of Digester	No. of Samples	Per Cent				
			CO_2	CH_4	H_2	O_2	CO
June 10–July 4	1	8	24	59	4.9	0.6	
July 22–Nov. 2	1	9	22	57	4.5	1.0	0.2
Nov. 9–Dec. 21	1	6	22	56	4.4	1.1	0.5
June 10–July 8	4	4	24	57	6.0	0.2	
July 21–Nov. 2	4	9	22	54	6.7	0.4	0.2
Nov. 9–Dec. 21	4	6	22	60	4.3	1.4	0.3
June 9–June 30	5	4	22	56	1.9	0.4	
Aug. 7–Nov. 2	5	9	23	51	6.3	0.7	0.2
Nov. 8–Dec. 21	5	6	22	53	2.2	0.7	0.2
June 9–July 15	6	4	23	59	6.0	0.5	
July 21–Nov. 2	6	10	22	56	7.1	1.0	0.2
Nov. 9–Dec. 21	6	6	22	55	3.8	0.5	0.2

These averages are for the periods before, during and after the addition of carbon in each of the digesters. Although the methane content of the gas drawn from digesters 1 and 6, while carbon was being added, is less than the methane content of the gas before carbon was added, yet the drop in the average methane content of the gas of digesters 1 and 6 is less than the drop in the methane content of the gas of digesters 4 and 5 for these two periods. During the period November 8 to December 21 when all digesters were receiving the same feeding of sludge, digesters 4 and 5 showed an increasing methane content of the gas, while digesters 1 and 6 showed a slightly decreasing content.

The low carbon dioxide content of the gas is due to absorption of the carbon dioxide by the water over which the gas was collected. Due to the lesser solubility of methane than carbon dioxide the absorption of carbon dioxide would tend to increase the percentage of methane reported.

Sludge and Supernatant Characteristics

Summaries of the characteristics of the fresh sludge added to the digesters, and of the sludges withdrawn from the digesters before, during and after the addition of carbon to digesters 1 and 6, are given in the following table.

Little change was noted in the volatiles of the withdrawn sludge during the tests. The hydrogen-ion concentration of the fresh sludge, and of the withdrawn sludge was very uniform throughout the duration of the tests. The hydrogen-ion concentration of the withdrawn sludge does not indicate that the addition of carbon made any change in the concentration.

The supernatants drawn from all digesters contained less than 1 per cent total solids, the per cent of volatile solids varying markedly

Summary Fresh Sludge Characteristics

Date 1936	Number Samples	Per Cent Solids		
		Aver.	Max.	Min.
May 22–July 20	49 Total Solids	3.7	5.4	1.5
July 21–Nov. 2	79	3.8	8.3	1.4
Nov. 3–Dec. 19	39	4.0	5.4	2.1
May 22–July 20	49 Volatile Solids	73.8	79.1	70.2
July 21–Nov. 2	79	72.9	80.2	64.6
Nov. 3–Dec. 19	39	76.7	81.9	72.5
May 22–July 20	49 pH	5.6	6.4	5.3
July 21–Nov. 2	79	5.6	6.1	5.2
Nov. 3–Dec. 19	39	5.7	6.2	5.2

Summary Digested Sludge Characteristics

Date 1936	Number Samples	Digester	Total Solids			pH		
			Ave. %	Max. %	Min. %	Ave. %	Max. %	Min. %
May 22–July 22	7	1	8.9	11.2	7.7	7.2	7.3	7.0
May 21–July 22	8	4	8.0	12.2	2.1	7.2	7.3	7.0
May 21–July 22	7	5	9.1	13.2	7.8	7.2	7.5	7.0
May 22–July 22	9	6	7.9	12.6	1.7	7.1	7.2	7.0
			Volatile Solids					
May 22–July 22	7	1	49.9	55.2	45.4			
May 21–July 22	8	4	51.7	54.1	47.4			
May 21–July 22	7	5	49.9	51.9	48.2			
May 22–July 22	9	6	50.8	52.6	46.8			
			Total Solids					
July 29–Oct. 30	9	1	9.6	16.5	1.8	7.2	7.4	7.1
July 30–Sep. 13	7	4	11.3	13.5	6.8	7.3	7.4	7.2
July 29–Oct. 30	10	5	9.7	12.5	5.9	7.3	7.4	7.1
July 30–Oct. 23	10	6	9.0	12.1	6.6	7.2	7.4	7.0
			Volatile Solids					
July 29–Oct. 30	9	1	53.8	61.8	49.0			
July 30–Sep. 13	7	4	52.1	53.9	50.3			
July 29–Oct. 30	10	5	52.8	61.7	50.7			
July 30–Oct. 23	10	6	55.7	60.7	51.0			
			Total Solids			pH		
Nov. 16–Dec. 11	3	1	8.8	12.6	6.3	7.0	7.1	7.0
Nov. 16–Dec. 7	3	4	8.7	11.1	7.1	7.1	7.1	7.0
Nov. 2–Dec. 16	2	5	7.0	7.7	6.4	7.0	7.0	7.0
Nov. 16–Dec. 7	2	6	6.3	6.7	5.9	7.1	7.1	7.0
			Volatile Solids					
Nov. 16–Dec. 11	3	1	54.2	57.9	47.6			
Nov. 16–Dec. 7	3	4	57.0	61.5	52.0			
Nov. 2–Nov. 16	2	5	56.7	57.4	56.3			
Nov. 16–Dec. 7	2	6	57.6	58.3	57.1			

depending upon the presence or absence of sludge particles in the supernatant. The hydrogen ion concentration was very uniform ranging from 7.0 to 7.3.

The digested sludges drawn from the digesters had an average total solids content of from 6 to 11 per cent, a volatile solids content from 50 to 58 per cent, and a hydrogen-ion concentration ranging from 7.0 to 7.5.

Reduction of Odors

During the early experiments when the small gallon digesters were being charged, and later in charging the fifty-five gallon digesters, the reduction of odor in the fresh carbon-charged sludge was very pronounced.

Conclusions

The sewage of Ithaca is primarily a domestic sewage. Such tests as have been made do not indicate that it differs materially from the average of domestic sewages.

The conclusions drawn from the investigations are based upon conditions at Ithaca, but it is felt that they apply to average domestic sewages.

1. The addition of activated carbon to fresh sludge reduces odor.
2. While the evidence is conflicting, the use of 5 to 15 p.p.m. of carbon in sludge digestion at 20° C, appears to yield more gas, than is produced when no carbon is used; at 28° C. this same advantage does not appear. When added to the sludge in greater amounts the carbon appears to reduce the amount of gas produced at all temperatures.
3. At 20° C. the presence of carbon in the sludge resulted, in completed digestion earlier than when no carbon was used. At 28° and 45° C. no advantage in this respect was shown.
4. The evidence indicates that the addition of activated carbon to sludge increases the methane content of the gas produced.
5. The addition of activated carbon to sludge increases the drainability of the sludge, the maximum influence in shortening the time of draining occurring when carbon is used at the rate of 30 p.p.m.
6. Little or no change in the hydrogen ion concentration of digested sludge due to the addition of carbon, was noted.
7. When used in small amount, less than 5 p.p.m., an increase in the temperature of the sludge was noted after adding carbon.

OXYGEN DEMAND STUDIES

By Jerome Burtle (with A. M. Buswell)

Illinois State Water Survey, Urbana, Illinois

The question of accurate quantitative analyses of sewage has long intrigued sanitary and analytical chemists. The very dilute character of wastes (domestic sewage about 99.95 per cent water) coupled with the heterogenous nature of the elements and compounds found therein make precise determinations well nigh impossible. Application of satisfactory tests which might be used as measures of the "strength" of a waste or of the degree of pollution of a stream have been especially difficult and those which exist today are generally considered to be unsatisfactory.

The discovery by Dupre[1] that the self-purification of streams is brought about by microorganisms in the water which destroy organic matter and use up dissolved oxygen in the process, served as the basis for the biochemical oxygen demand test which is the standard today.[2] This determination, employing as it does the dilution technic of Adeney[3, 4, 5, 6, 7] and the Rideal-Stewart[8] modification of the Winkler[9] dissolved oxygen test, was first officially recognized by the Royal Sewage Commission in 1913[10] and has persisted with a few changes until it appears as the present standard method.[2]

In his early work reported in the above references Adeney also suggested use of a direct absorption technic for measuring the amount of oxygen utilized during biochemical purification. This procedure though simple and direct, gained little favor because of the difficulty in finding satisfactory apparatus.[11] The direct absorption technic was revived by Sierp[12] and by Symons and Buswell[13] but the method failed to catch popular fancy. In a recent publication Burtle and Buswell[14] described the use of the Nordell machine, now called the Odeeometer, for the determination of oxygen demand of trade wastes. In this paper direct absorption as carried out in the Odeeometer is applied to domestic sewage.

A survey of recent literature shows a definite increase in interest in chemical means of measuring degree of pollution due principally to work by Mills[15, 16] and by Lovett and Garner.[17] Moist combustions with collection of carbon dioxide and subsequent calculation of the amount of carbon present were first successfully carried out by Messinger.[18] The method has been improved and moist combustion tests have recently been applied to sewage by Mohlman and Edwards,[19] the investigators mentioned above, and Heukelekian and Rudolfs.[20] The only standard chemical method for estimating degree of pollution is the oxygen consumed from permanganate test as presented in Standard Methods.[21]

This paper reports a survey of the following methods which might be used for measuring degree of pollution; the dilution B.O.D., oxygen

consumed from permanganate, direct absorption B.O.D., and moist combustions.

Experimental

Comparison of Dilution and Direct Absorption B.O.D.'s

For this work dilution B.O.D.'s were carried out in accordance with the directions given in Standard Methods.[2] All direct absorption measurements were carried out in the Nordell Odeeometer. In a previous paper Burtle and Buswell[14] described the Odeeometer and explained its adaptation to the determination of B.O.D. They showed that with domestic sewage two definite peaks occur in the oxygen demand curve as plotted from Odeeometer data; the first occurring shortly after the start, and the second, marking the beginning of the

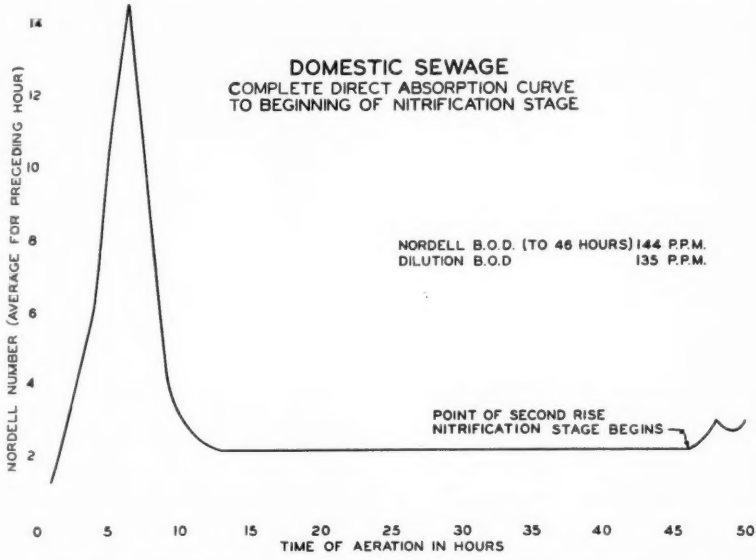

FIG. 1.—Curve showing rate of oxygen demand of domestic sewage by Odeeometer, extended to start of nitrification stage.

nitrification stage, occurring forty-five to fifty hours after the beginning of aeration.

The first consideration in this investigation was to attempt to again show the point of second rise or nitrification stage. Accordingly, a sample of Champaign-Urbana domestic sewage showing no trace of nitrates was placed in the Odeeometer and aerated. Readings were made every hour. The results are shown in Fig. 1. This curve shows the second rise at the forty-sixth hour of aeration. At this time the calculated Nordell number (p.p.m. of oxygen absorbed per hour) showed a definite increase and the nitrites rose from 0 to .02 p.p.m.

The significant feature of this curve is that the second rise occurred at approximately the same hour that it occurred on the sample investi-

gated by Burtle and Buswell in their previous work.[14] Moreover, B.O.D. values calculated to this point agreed closely in both cases with dilution B.O.D.'s obtained in parallel tests.

It occurred to us, therefore, that direct absorption B.O.D.'s closely confirming 5 day dilution B.O.D.'s might be calculated by assuming that the nitrification stage occurred always at the forty-sixth hour. It would then be necessary simply to evaluate the first part of the rate curve, making hourly readings only until the Nordell number reached a constant value (generally 8–12 hours). Extrapolation along the straight line given by this constant value (see Fig. 2) to the forty-sixth

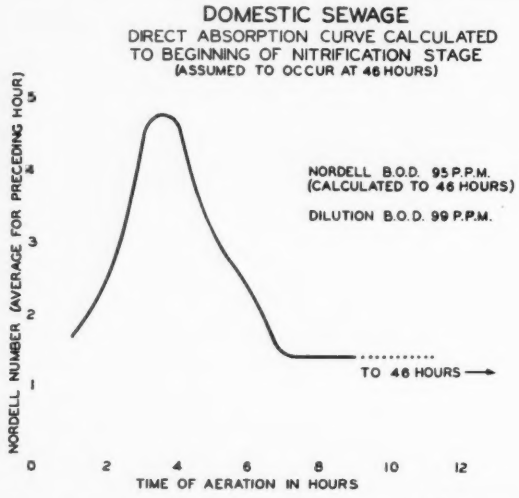

FIG. 2.—Curve of rate of oxygen demand of domestic sewage by Odeeometer, showing extrapolation to nitrification stage.

hour should give a satisfactory B.O.D. Results given in Table I expressing 5-day dilution values and direct absorption B.O.D.'s calculated as explained above show excellent agreement in all but the last case. It will be noted that the percentage error in all cases, excepting sample 6 under filtered sewage, is less than ten. This is within the limits of accuracy found by Theriault [22] to exist between various dilutions of the same sample tested by the standard dilution method. Even filtered sample 6 is not far out of line and it is probable that most of the error is in the dilution rather than the direct absorption result. It will be noted that the direct absorption value is much more consistent with the other values for filtered sewage than is the dilution value.

In the determination shown in Fig. 3, readings were made only until the first peak of the curve was evaluated. No more readings were made until the thirteenth hour of aeration when it was assumed that the Nordell numbers would have reached a constant value. The curve was sketched through the observed points and the intervening values taken from the graph. Agreement was close in this case also. This

TABLE I

Unfiltered sewage sample number	Direct adsorption B.O.D. (p.p.m.)	Dilution B.O.D. p.p.m.	Difference p.p.m.	% difference
1	123	121	2	1.6
2	144	135	9	6.3
3*	65	60	5	7.7
4	113	125	12	9.6
5	95	99	4	4.0
6	141	153	12	7.8
7	134	131	3	2.2
Filtered sewage				
1	76	74	2	2.6
2	90	95	5	5.3
3	115	113	2	1.7
4	98	94	4	4.1
5	96	93	3	3.1
6	137	180	43	23.9

* This sample was taken shortly after a heavy rain which explains the very low B.O.D.

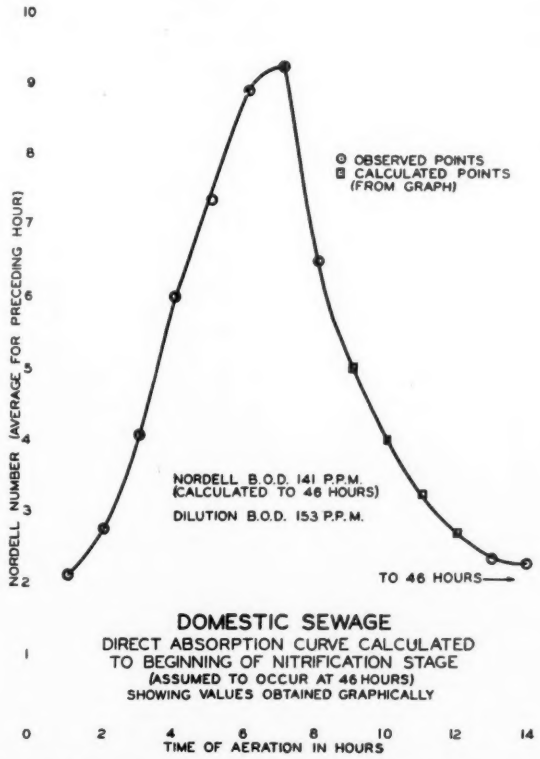
NORDELL NUMBER (AVERAGE FOR PRECEDING HOUR)
TIME OF AERATION IN HOURS
OBSERVED POINTS
CALCULATED POINTS (FROM GRAPH)
NORDELL B.O.D. 141 P.P.M. (CALCULATED TO 46 HOURS)
DILUTION B.O.D. 153 P.P.M.
TO 46 HOURS
DOMESTIC SEWAGE
DIRECT ABSORPTION CURVE CALCULATED TO BEGINNING OF NITRIFICATION STAGE (ASSUMED TO OCCUR AT 46 HOURS) SHOWING VALUES OBTAINED GRAPHICALLY

FIG. 3.—Curve of rate of oxygen demand of domestic sewage by Odeeometer, showing method of determining missed values graphically.

points out that hourly readings are necessary only to establish the maximum value in the first peak of the curve and to determine the point at which constant Nordell numbers are obtained. The rest of the curve may be sketched in and valid values for hourly Nordell numbers may be obtained from which a fairly accurate B.O.D. may be calculated. The advantages of such short cuts might become important in routine analysis.

It is evident from the above results that the Nordell Odeeometer offers a means of determining B.O.D. values which are quite comparable to those obtained by the dilution method. With the direct absorption method the time required is cut from five days to a matter of ten to twelve hours. Furthermore, no dilution is required and the large starting sample (four litres) cuts down sampling error. Unfortunately, values obtained are as empirical as those in the dilution method but are obtained with greater ease, speed, and consistency.

Chemical Oxidations

The oxygen consumed from permanganate test represents the only standard chemical method for measuring degree of pollution. In the course of some work involving fermentation of pure compounds, carried out in this laboratory, it was noted that materials high in volatile acids were frequently very low in oxygen demand as shown by the oxygen consumed test. Accordingly, a series of pure solutions of acetic, propionic, and butyric acids was prepared and standardized. Each of these solutions was tested for its oxygen demand by means of the oxygen consumed test. Results are shown in Table II.

Table II

Acid	p.p.m. acid in solution	p.p.m. oxygen required (theoretical)	p.p.m. oxygen consumed	% oxidation
Acetic	1047	1117	266	23.8
	1000	1067	200	18.7
Propionic	1029	1557	30	1.9
	1058	1601	60	3.1
Butyric	993	1805	80	4.4
	993	1805	70	3.8

These results show that the "oxygen consumed" determination is entirely inadequate in estimating the oxygen demand of volatile acids. This fact would seriously impair the usefulness of the test when applied to certain trade wastes which are high in these acids. Moreover, by inference from the above results, we may easily imagine other compounds which would be resistant to oxidation by permanganate under the mild conditions of this test. These data indicate the unsatisfactory nature of this test as a moist combustion method. Further results ob-

tained by it are reported but only to give a complete picture of the oxygen demand methods as applied to sewage.

In studying moist combustion as a means of determining the strength of sewage it was first necessary to choose an oxidizing agent capable of completely oxidizing the organic matter in sewage. This entailed the selection of a reagent which would, in the presence of large amounts of water, break down the polluting compounds with the quantitative production of carbon dioxide. Perusal of the literature indicated that three were particularly promising. These were: the chromic, sulphuric, phosphoric acid mixture of Schollenberger;[23] potassium persulphate suggested by Franz and Lutze;[24] and potassium permanganate in strongly acidic solution.[25] To complete the picture a fourth reagent, alkaline permanganate,[26] was also investigated.

To determine the efficiency of each of the oxidants, eleven pure compounds were tested with each reagent. These pure compounds included: acetic acid; benzene; chloracetic acid; cellulose (filter paper); glycerol; phenylalanine; potassium acid phthalate; sucrose; phenol; stearic acid; and sodium stearate (stearic acid + excess NaOH).

The apparatus used in studying the moist combustion reactions of pure compounds was a simple one and is shown in Fig. 4. The reaction

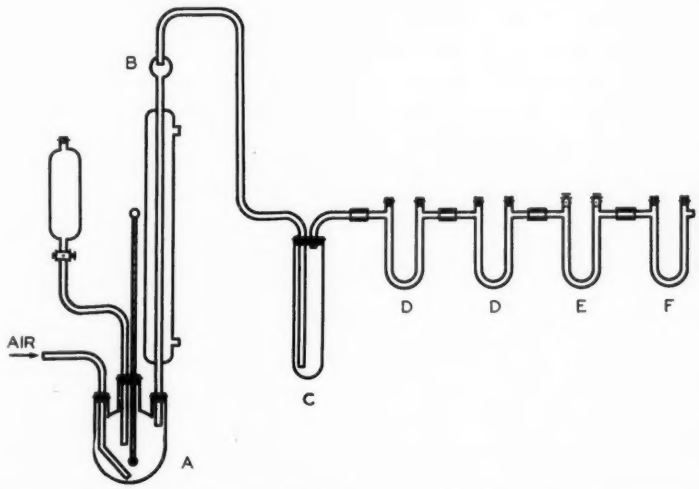

FIG. 4.—Diagram of apparatus used in the moist combustion of pure compounds.

flask *A* was fitted with a thermometer and a separatory funnel for the addition to reagents and was connected to a reflux condenser. Carbon dioxide-free air was bubbled through the reaction mixture through the air tube shown. The evolved gases were carried through the condenser and fume trap *B* into a purification train. Tube *C* contained a saturated aqueous solution of CrO_3 for use with the reagents employing sulphuric acid. Its function, when used, was to absorb acidic oxides of sulphur. The U tubes *D* contained anhydrone for the re-

moval of water vapor and *E* was an ascarite bulb for the collection of carbon dioxide. Tube *F*, containing soda-lime, protected the ascarite from back diffusion of the atmosphere. When chloracetic acid was under investigation a trap containing acidified potassium iodide was introduced into the train to remove the chlorine from the gas stream.

Phenylalanine alone of the compounds contained nitrogen. Destruction of this compound would undoubtedly result, as the first step, in the hydrolysis of the amino group according to the equations:

$$(1)\ C_6H_5CH(NH_2)CH_2COOH + H_2O \xrightarrow{(H_2SO_4)} C_6H_5CH(OH)CH_2\text{-}COOH + NH_3$$

$$(2)\ 2NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$$

Repeated blanks run on ammonium sulphate showed no increase in weight of the ascarite. Oxides of nitrogen, therefore, were of no significance in these pure compound determinations.

Frequent blanks were run on the reagents and the blank values, which included the weight increase due to any unremoved sulphur oxides and any carbon dioxide from the reagents, were deducted from the increase in weight of the ascarite tube during a complete run.

Chromic Acid.—The oxidizing agent consisted of a mixture of chromic, sulphuric, and phosphoric acids as suggested by Schollenberger.[23] The procedure was as follows:

A portion of the compound containing ten to thirty milligrams of carbon was placed in the reaction vessel and carbon dioxide-free air bubbled through the apparatus for fifteen minutes to sweep it clear of carbon dioxide. The previously weighed ascarite absorber was then connected and the oxidizing mixture added to the reaction flask. As recommended by Friedemann and Kendall,[27] 2 c.c. of concentrated sulphuric acid was added for each cubic centimeter of water present in the sample. The contents of the flask were brought to a gentle boil and held at that temperature for two hours. Heating was then discontinued but the air was allowed to bubble through the system for an additional half hour. At the end of that time the ascarite tube was removed from the train, wiped carefully, and weighed. The weight of carbon dioxide absorbed minus the blank value was calculated to carbon.

Acid Potassium Permanganate.—Use of this reagent was suggested by DeNardo.[25] For the investigations described in this paper a saturated aqueous solution of $KMnO_4$ and a high concentration of H_2SO_4 were used as the oxidizing mixture. The procedure employed was as follows:

A sample of the compound containing the same amount of carbon as used in the chromic acid oxidation was placed in the flask and the train swept out as before. The $KMnO_4$ and the sulphuric acid were mixed, allowed to cool, and then added to the reaction vessel. This had to be done because mixing of the two chemicals in the reaction flask caused a sudden evolution of so much heat that acetic acid vapors were driven out of the flask with the gas stream and stearic acid was vaporized and

condensed out in the solid state in the condenser tube. After the addition of the oxidizing agents the reaction mixture was gently boiled for one hour. The train was swept out with carbon dioxide-free air for fifteen minutes after heating was discontinued and then the ascarite tube was weighed as before.

Potassium Persulphate.—The method outlined by Osburn and Werkman [28] which is applicable in the presence of chlorides, large amounts of water, and of chlorine-sulphur-and nitrogen-containing compounds, was adopted as a model.

A quantity of carbon-containing material sufficient to liberate between 100 and 300 milligrams of carbon dioxide was placed in the reaction flask and carbon dioxide-free water added to make a total of about 180 c.c. Ten grams of powdered potassium persulphate was added and the mixture stirred until all the persulphate was dissolved. A 10 c.c. portion of 4 per cent $AgNO_3$ was introduced to serve as a catalyst and the apparatus was swept out with carbon dioxide-free air for fifteen minutes. The previously weighed ascarite tube was placed in position and the reaction flask immersed in water at a temperature of 70°–80° C. At this point Osburn and Werkman discontinue the passage of air into the apparatus but our experiments were more successful if air was allowed to bubble through all during the run.

As the reaction mixture became warm a black deposit of silver peroxide formed and at 70° C. a lively evolution of oxygen gas began. The temperature was kept between 70° and 80° C. until the solution cleared up and evolution of gas had stopped. The reaction flask was then removed from the water bath and the contents brought to a gentle boil. The boiling was continued for fifteen minutes and the ascarite bulb was then reweighed.

The reaction may be expressed by the equation:

$$K_2S_2O_8 + H_2O \longrightarrow 2KHSO_4 + O$$

Since the reaction becomes acid during the process, there is no difficulty in driving all of the carbon dioxide out of solution.

Alkaline Potassium Permanganate.—The system of carbon dioxide absorption could not, of course, be applied with an alkaline reagent, so investigations with this oxidizing agent were conducted volumetrically. The method used was a modification of the one suggested by Kingscott and Knight [26] for the determination of phenol. To a measured amount of the material under investigation were added one gram of sodium bicarbonate and an excess of potassium permanganate. For these determinations permanganate solutions approximately one-tenth normal were used. The mixture was boiled gently for fifteen minutes, allowed to cool, and filtered through sintered glass to remove the manganese dioxide formed in the reaction. The filtrate was acidified, heated to 60° C. and decolorized with sodium oxalate. The colorless solution was back titrated with potassium permanganate.

Results of the reactions between the oxidizing agents and the pure compounds are given in Table III. This table shows that all the com-

TABLE III

Compound	% oxidation using CrO_3, $H_2SO_4+H_3PO_4$	% oxidation using $KMnO_4$ $+H_2SO_4$	% oxidation using $K_2S_2O_8$	% oxidation using alkaline permanganate
Acetic acid	99.5	99.5	98.8	15.6
	99.0	98.6	98.3	13.8
	97.3	98.6	99.0	15.0
Benzene	38.2	10.8	26.5	1.4
	30.7	13.8	30.4	1.2
	32.3	12.2	25.1	1.6
Chloracetic acid	99.7	91.5	99.5	8.0
	98.0	91.5	97.5	8.0
	98.5	90.5	99.5	9.6
Cellulose	95.1	97.1	4.4	14.3
	96.5	93.8	3.6	14.7
	96.1	95.1	4.5	14.2
Glycerol	97.5	93.7	98.2	93.5
	97.0	94.7	96.2	92.0
	95.2	96.0	96.2	93.0
Phenylalanine	99.3	98.6	99.0	24.5
	99.0	99.5	99.3	24 8
	96.3	99.1	96.5	24.7
Potassium acid phthalate	99.3	99.0	96.0	7.7
	99.2	99.4	95.0	8.0
	99.0	99.3	94.9	8.4
Phenol	97.6	100	99.6	99.0
	97.1	99.2	97.2	99.2
	96.6	99.8	97.2	99.3
Stearic acid	99.2	4.5	5.0	25.2
	99.7	4.1	8.4	25.9
	98.3	3.8	6.0	25.3
Sodium stearate	96.5	83.9	29 6	25.2
	96.9	75.3	31.7	25.9
	96.5	82.0	30.9	25.3
Sucrose	99.7	96.9	99.0	97.2
	98.2	96.8	98.3	97.4
	98.5	94.2	99.8	97.1

pounds studied, excepting benzene, were effectively oxidized by the chromic acid reagents. Benzene is not only resistant to oxidation but is highly volatile so some arrangement for a vigorous vapor phase oxidation will probably have to be made to assure complete combustion of compounds of this type. Acid permanganate, though giving good results with most compounds, failed on benzene, stearic acid, and

sodium stearate. Potassium persulphate was effective only against compounds which are water soluble. Water insoluble and colloidal compounds were attacked only slightly. Alkaline permanganate, under these conditions, was effective only against the more easily oxidized materials, namely, glycerol, phenol, and sucrose. It was the least efficient of the four oxidants.

The data in Table III indicate that, of all the oxidizing agents investigated, the chromic, phosphoric, sulphuric acid mixture was the most promising. This reagent, accordingly, was employed in the investigations carried out on sewage.

Moist Combustions Applied to Sewage.—Having chosen the oxidizing agent to be used in our comparative tests it became necessary to find an apparatus which would permit the application of the oxidant to a study of sewage. The simple apparatus used in the oxidation of pure compounds would not, of course, lend itself to use on polluted waters because of the presence in these wastes of compounds of nitrogen and sulphur, both organic and inorganic which, on oxidation, would contribute acidic oxides of these elements to the gas stream. The problem, then, was to discover a method of absorbing preferentially, the oxides of nitrogen and sulphur or to find a method which would not be disturbed by the presence of such oxides in the gas.

Perusal of the literature of such oxidation disclosed only one suggestion for completely removing halogens, sulphur oxides, and nitrogen oxides from the gas and allowing the carbon dioxide to pass on into the absorption tube. This was a method suggested by Desgrez and Vivario,[29] which involved an extremely complicated purification train. In order to avoid such a complex apparatus we turned our attention to locating a method which would not be affected by the presence of oxides of sulphur and nitrogen. Such a procedure is described by Mills.[15, 16] Lovett and Garner[17] report the application of the Mills method to sewage with some success and after due consideration it was chosen as the best available for our investigations. A few modifications, however, seemed advisable and these were made. The reagent used by Mills consists of aqueous chromic acid and a three to one ratio of sulphuric acid to water. We retained the chromic, phosphoric, sulphuric acid reagent of Schollenberger and used a two-to-one ratio of sulphuric acid to water. We also adopted a longer reaction period than that suggested by Mills because no air is bubbled through the apparatus during the oxidation, the heat of reaction alone forcing the gas through the absorption towers. In view of this fact the heating time was extended to three hours to assure complete collection of the carbon dioxide.

The reaction flask and condenser were exactly the same as used in the pure compound work and as the gas left the condenser it was passed through a scrubber containing a saturated aqueous solution of chromic acid to remove the oxides of sulphur. From this scrubber the gas was led successively through three Erlenmeyer flasks, each containing barium hydroxide. A soda lime tube protected these flasks

from back diffusion of the atmosphere. The carbon dioxide was precipitated as barium carbonate, which was weighed at the end of the run. Such an arrangement obviates the necessity of remvoing halogens and oxides of nitrogen because these compounds do not form precipitates with barium hydroxide.

Determinations were carried out according to the following procedure: A 50 c.c. sample of the sewage under examination was placed in the reaction flask and 1 c.c. of a saturated aqueous solution of silver sulphate added. With the flask connected to the condenser and immersed in a bath of cold water, the phosphoric and sulphuric acid constituents of the oxidation mixture, including the excess of 2 c.c. of sulphuric acid for every c.c. of water in the flask, were cautiously introduced. Carbon dioxide-free air was then bubbled through the mixture for thirty minutes to remove dissolved and inorganic carbon dioxide. The barium hydroxide absorption flasks were then connected to the condenser, the chromic acid added, and heating commenced. At this point the external gas stream was shut off and the contents of the reaction flask brought to a gentle boil. The absorption tubes were placed in a water bath held at 80°–100° C. to allow coagulation of the barium carbonate formed. The reaction was allowed to proceed for three hours when the absorption flasks were disconnected and a second soda lime tube connected to the unprotected end. After a sufficient cooling period the contents of the absorption vessels were filtered through a sintered glass crucible previously weighed. When filtration was completed the precipitate was washed from six to eight times with boiling distilled water to free it of adsorbed barium hydroxide. The crucible was then dried and weighed.

Mills pointed out that the results obtained by this method were extremely precise and reproducible. A few preliminary investigations were conducted to satisfy ourselves of the reproducibility of results by our modification. For this purpose two runs were carried out simultaneously in two different oxidation trains, each using portions of the same sample of sewage. Blank runs were also conducted in the two trains using 50 c.c. of distilled water in place of the sewage. Satisfactory confirmations were obtained in the duplicate runs both with blanks and with sewage samples Results of two blank determinations are shown in Table IV while results from several duplicate analyses of sewage are shown in Table V.

The blank value expressed in Table IV seems high but confirmations between duplicates is good. Other blanks run from time to time closely confirmed the two shown. Moreover, Mills' blank value was of the same order. We concluded, therefore, that the blank, though high, was accurate and entirely adequate. A value representing an average of all the blank determinations was deducted from the values obtained on sewage.

Results of the duplicate determinations on sewage are shown in Table V. At first glance they seem a bit rough, but in comparison with other tests on sewage they are really very good. Various dilutions of

TABLE IV

Weight of barium carbonate in grams		Difference (gms.)	% difference
Train A	Train B		
.0357	.0364	.0007	1.9

TABLE V

Organic carbon (p.p.m.)		Difference (p.p.m.)	% difference
Train A	Train B		
186	188	2.0	1.0
199	192	7.0	3.5
86	84	2.0	2.3
102	98	4.0	3.9
134	122	12.0	8.9
(*a*) 3850	3770	80.0	2.1

(*a*) This sample was not domestic sewage but liquor from an anaerobic digestion tank engaged in the decomposition of soy beans.

the standard biochemical oxygen demand test seldom confirm each other more closely than five per cent and often miss as far as fifteen to twenty per cent. In the light of such facts, therefore, confirmations between duplicates of the chemical oxidations may be called very good. Closer confirmations could be obtained if an all glass reaction flask were used without rubber stoppers. This would eliminate possible oxidation of small amounts of rubber and would do away with the possibility of leaks due to disintegration of the stoppers by the acidic fumes arising from the reaction vessel.

As a final step in the study, sewage samples were investigated by all four of the tests for oxygen demand. Each sample of sewage was analyzed by moist combustion, direct absorption, dilution biochemical oxygen demand, and oxygen consumed from permanganate. The first two tests were applied as has already been explained. The other two were carried out in accordance with the directions given in Standard Methods.[2, 21] The results, some of which have been presented in part in previous tables, are tabulated in complete form in Table VI and give some interesting information on the correlation which may be expected between the various determinations and the degree of consistency shown by each.

Analysis of the results as expressed in Table VI brings to light several interesting facts. In the first place there is no numerical correlation between the results obtained by the moist combustion method and those of any of the other tests. This is to be expected because the moist combustions measure the amount of carbon present in the sample while all of the other tests measure the amount of oxygen necessary to oxidize some part of this carbon. There is, in general, a loose sort of consistency between all of the tests, that is, an appreciable increase or de-

TABLE VI

Organic carbon (p.p.m.) (Moist combustion)	Oxygen consumed (p.p.m.) (from $KMnO_4$)	Dilution B.O.D. (p.p.m.) (Standard Methods test)	Direct absorption B.O.D. (Nordell Odeeometer)
Unfiltered sewage			
196	114	121	123
187	101	135	144
(*a*) 52	26	60	65
160	63	125	113
128	48	99	95
172	71	153	141
164	106	131	134
Filtered sewage			
85	25	74	76
133	46	95	90
146	56	94	98
150	66	113	115
170	46	93	96
178	84	180	137

(*a*) This sample was taken shortly after a heavy rain which explains the anomalously low result.

crease in one is reflected by an increase or decrease in the others. The consistency, such as it is, between chemical oxidations (moist combustion) and direct absorptions seems distinctly better than that between the combustions and dilution B.O.D.'s. The last result in Table VI shows this clearly. Here we have a consistent rise in both combustion and direct absorption B.O.D. results, but the rise in the dilution value is entirely unexpected and unexplainable. Such anomalously high values as well as occasional low results are repeatedly encountered in running dilution B.O.D.'s as a routine and represent one of the weaknesses and great annoyances of this test.

The oxygen consumed test, while showing the same general consistency as the other determinations, gives values much lower than either of the other two oxygen demand tests when applied to domestic sewage. Previous work in this laboratory [14] has shown that with some types of trade wastes the oxygen consumed values are higher than those obtained either in the dilution or the direct absorption oxygen demand determinations. Such results show the erratic nature of the oxygen consumed test as outlined by Standard Methods.

Summary and Conclusions

Investigations were carried out on methods for determining the oxygen demand of polluted waters. Methods used included: a moist combustion; the dilution biochemical oxygen demand; the oxygen consumed test; an oxygen demand obtained by direct absorption methods. Work on pure compounds indicated that an oxidizing mixture of chromic, phosphoric and sulphuric acids was an excellent reagent for

oxidation of organic material. This reagent was used in the moist combustions.

Sewage samples were analyzed by all of the methods mentioned above. Results of the dilution and absorption tests agreed closely in most cases but results obtained in the oxygen consumed test were lower than those obtained in the other two oxygen demand determinations. Duplicate determinations by the moist combustion oxidation agreed very well considering the crudity of the apparatus. On the whole a loose consistency was noted between the results of all the tests.

From the results of the investigations several definite conclusions seem logical:

1. The oxygen consumed from permanganate test seems to give only partial oxidation when applied to domestic sewage. When applied to trade wastes results by this determination are erratic due possibly to the presence of chemical reducing agents. It may, therefore, be concluded that this test is valueless as an absolute measure of the oxygen demand of polluted waters. Its use seems definitely limited to differential determinations, *i.e.*, determinations of the efficiency of a treatment process where the results are desired very quickly. The writers recommend that this test be excluded from Standard Methods or included only with the reservations suggested above.

2. The dilution B.O.D. is distinctly an empirical determination. It measures only the amount of oxygen taken up from a dilution water of a certain type in a certain definite length of time under a particular set of conditions of incubation. The values obtained have meaning only as long as the conditions remain fixed. It is possible, however, to reproduce these values in a direct absorption apparatus, the Nordell Odeeometer. Results obtained with this machine are just as empirical as those obtained in the dilution test, but the direct absorption procedure presents three distinct advantages; the results can be obtained in eight to ten hours instead of five days, no dilution is required, and a larger sample is used so that sampling errors are minimized. If such limited values must be used to define the degree of pollution of water the Odeeometer presents a means of obtaining them which is easier to handle, more rapid, and less susceptible to the production of unexplainably high or low results.

3. Moist combustions of the type described in this paper and in those of previous investigators give promise of becoming useful in sewage determinations. Values obtained are reproducible in duplicate and they show a certain loose consistency when compared with the results given by other oxygen demand tests. The absolute values obtained, though accurate from the standpoint of reproducibility, must be regarded with some suspicion until further investigation proves, beyond reasonable doubt, that the results obtained represent all of the organic carbon and only the organic carbon. Such investigations are now being launched by the writers.

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Plant Operation

PROGRESS OF SEWAGE TREATMENT IN NEW YORK CITY *

By Richard H. Gould

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For the past several years Commissioner Binger or some member of the Department of Sanitation has given some sort of a discussion of the New York City sewage disposal problem before this Association at the annual meeting in New York. This being so, it is felt that most of you are fairly well acquainted with our problem and what we are trying to do about it. For that reason I shall touch on the general features but briefly in order to show you more of what has been done in the past year.

As you may recall, there are a number of plants being operated in the city. The most important of these is the Coney Island works with a present design capacity of 35 m.g.d. and providing for sedimentation, sludge digestion and seasonal chemical treatment and chlorination. There are thirteen older plants, most of which will ultimately be abandoned or altered substantially. Of these, eight are of the fine screening type, three of which are provided with chlorination facilities. There is one small septic tank, one inadequate sedimentation plant and three with coarse screening only. The total average flow being treated in these plants amounts to about 120 m.g.d., which is about 12 per cent of the total sewage being discharged to the harbor from the city. Because of the limited degree of treatment given, only about 3 per cent of the total sewage solids of the city are captured. The Coney Island plant during the summer months alone accounts for about 40 per cent of the total removal.

The tentative program along which we are working calls for the construction of some 38 separate treatment works. Of these the Coney Island plant has been built. The Wards Island works are under construction and the first contract has been let on the Tallman's Island Works.

In addition to the Tallman's Island works, design authorizations have been granted for intercepting sewers in College Point leading to the Tallman's Island plant, the Ditmers Boulevard intercepting sewer to divert sewage from the west shore of Flushing Bay to the North Beach Screening Plant and the reconstruction and enlargement of the North Beach Screening Plant.

* Presented Before the Ninth Annual Meeting of the New York State Sewage Works Association, New York City, January 22, 1937.

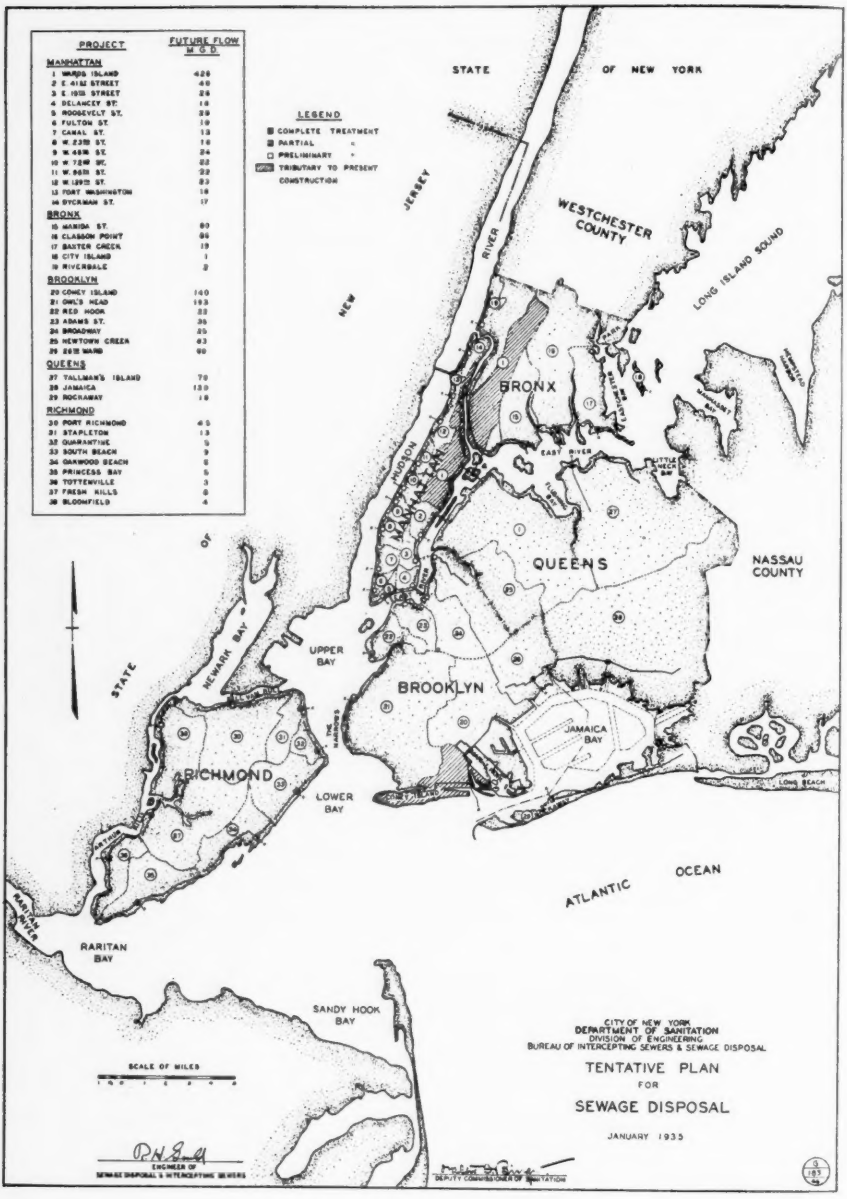
PROJECT
FUTURE FLOW M G D
MANHATTAN
1 WARDS ISLAND 426
2 E. 41st STREET 40
3 E. 19th STREET 24
4 DELANCEY ST. 18
5 ROOSEVELT ST. 29
6 FULTON ST. 19
7 CANAL ST. 13
8 W. 23rd ST. 16
9 W. 42nd ST. 24
10 W. 72nd ST. 22
11 W. 96th ST. 22
12 W. 129th ST. 23
13 FORT WASHINGTON 16
14 DYCKMAN ST. 17
BRONX
15 MARIDA ST. 80
16 CLASSON POINT 86
17 BAXTER CREEK 19
18 CITY ISLAND 1
19 RIVERDALE 3
BROOKLYN
20 COWEY ISLAND 140
21 OWLS HEAD 193
22 RED HOOK 22
23 ADAMS ST. 36
24 BROADWAY 25
25 NEWTOWN CREEK 63
26 26th WARD 90
QUEENS
27 TALLMAN'S ISLAND 70
28 JAMAICA 130
29 ROCKAWAY 19
RICHMOND
30 PORT RICHMOND 45
31 STAPLETON 13
32 QUARANTINE 5
33 SOUTH BEACH 9
34 OAKWOOD BEACH 6
35 PRINCESS BAY 5
36 TOTTENVILLE 3
37 FRESH KILLS 6
38 BLOOMFIELD 4
LEGEND
COMPLETE TREATMENT
PARTIAL
PRELIMINARY
TRIBUTARY TO PRESENT CONSTRUCTION
STATE OF NEW YORK
NEW JERSEY
HUDSON RIVER
WESTCHESTER COUNTY
LONG ISLAND SOUND
BRONX
EAST RIVER
QUEENS
NASSAU COUNTY
NEWARK BAY
UPPER BAY
BROOKLYN
JAMAICA BAY
RICHMOND
LOWER BAY
ATLANTIC OCEAN
RARITAN RIVER
RARITAN BAY
SANDY HOOK BAY
SCALE OF MILES
CITY OF NEW YORK
DEPARTMENT OF SANITATION
DIVISION OF ENGINEERING
BUREAU OF INTERCEPTING SEWERS & SEWAGE DISPOSAL
TENTATIVE PLAN
FOR
SEWAGE DISPOSAL
JANUARY 1935
ENGINEER OF SEWAGE DISPOSAL & INTERCEPTING SEWERS
DEPUTY COMMISSIONER OF SANITATION

FIG. 1.

The above work, including that on Tallman's Island, is being advanced at this time in order to remove sewage discharges from Flushing Bay. This is particularly important now as the site of the World's Fair to open in 1939 is located at the head of Flushing Bay. Present conditions of pollution here would prove intolerable at that time. The work is all a part of the ultimate scheme, with the exception of the reconstruction of the North Beach Screening Plant, which is for temporary use pending the extension of the Wards Island plant to serve this section of Queens.

We are also engaged in the design of a 65 m.g.d. activated sludge plant at the site of the present Jamaica Screening Plant located on Jamaica Bay.

Something over $30,000,000 has been spent or is available for plans and for work now under contract in our program for new works. It is estimated that in addition thereto about $100,000,000 will be required to furnish treatment to all of the present flows and, ultimately, in order to provide for the extension of works to serve expected growth in population, perhaps another $70,000,000 will be needed. This is based on an ultimate sewage disposal program of about $200,000,000.

In terms of the program required for the present flows it would appear that New York City has already appropriated or spent funds for plans and construction up to the extent of about one-fourth of the total required and upon the construction of works under design will have raised the amount to about one-third of the total required.

The Wards Island construction was started in 1931, but held up because of financial conditions by 1933 after completing contracts amounting to about $4,500,000. No further important construction work was done until early in 1935 when largely because of P.W.A. grants the Coney Island work was started and in the fall construction was resumed on the Wards Island project.

Both projects were started under considerable pressure. At Coney Island, the settling tanks, pumping facilities and outlet piping were built and placed in operation in 104 days after the contractor was ordered ahead so that they were in use during the 1935 bathing season. The works are only now being completed, having been retarded by unfortunate conditions in connection with the electrical work. However, sewage has been treated continuously since July 1, 1935 and has resulted in a tremendous improvement in conditions along Coney Island and Shellbank Creeks, about which Mr. Donaldson will tell you in greater detail.

There is one unique development that may be of passing interest. The new plant at Coney Island replaced three old installations dating back to the late 80's and early 90's. We have compared the cost of operation of the old system during the first year that they were taken over by us in 1932 with the cost of the new system in 1936. This comparison indicates a probable annual saving under the new system in the neighborhood of $50,000 or about one-third of the total involved.

Because of certain understandings between the city administration and Washington, contracts for the Wards Island work were drawn up calling for continuous work during 24 hours of the day, with certain exceptions. This resulted in considerable pressure on our organization and a greatly accelerated program.

At the present time there are some 34 contracts in various stages of completion. Of the $21,000,000 contract allowance about 45 per cent has been completed. The Manhattan intercepting sewers are about 80 per cent complete; those in the Bronx to Jerome Avenue, 92 per cent complete; the Bronx tunnel was holed through on December 6 and is now being lined; the Manhattan tunnel has reached the fault zone under the Harlem River from both headings. Supplementary borings from the tunnel headings indicate that conditions here are much worse than were anticipated from earlier surface borings, and it is probable that the tunnel will have to be lowered from its present depth of 300 feet to a depth of over 500 feet for the 700 feet remaining in this bore.

The grit chamber substructures in Manhattan and the Bronx are essentially complete and steel is up for the superstructures. On Wards Island the substructures of the pump and blower house, administration building and heating buildings are well advanced. Large air and sewage piping is being installed and the superstructures of the sludge pumping stations and operating galleries have been started. The main pumping and blower units are being fabricated and contract work has started on three 1500 ton sludge vessels.

It is expected that the works will be ready for operation by the latter part of 1937.

PRELIMINARY OPERATIONS OF THE CONEY ISLAND SEWAGE TREATMENT PLANT *

By Wellington Donaldson

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Interest attaches to the Coney Island plant mainly for two reasons. It is the largest of the modern treatment works now operating in this country which was designed to use seasonal chemical treatment. Also, this plant exemplifies a rather interesting recrudescence of chemical treatment in the New York area, for chemical plants for treating sewage with lime, ferric chloride and chlorine were installed in the City of Brooklyn in 1886 and at this particular site (Caisson No. 4), in 1892. It is not the purpose here to trace the causes for disuse and abandonment of the early chemical plants nor to discuss the reasons underlying the selection of chemical treatment at this new plant. These reasons have been stated elsewhere at some length. Likewise, a description of the new plant is deemed unnecessary here.

With the knowledge generally that the Coney Island plant has been in service for some time, there has been a desire to know just what results have been obtained by treatment. An effort will be made in this paper to supply such information.

1935 Operation

Sewage was turned into the plant July 1, 1935, and pre-chlorination treatment was given during the months of July, August, September and October using liquid chlorine to the capacity of the machines available (some 900 lb./day), with calcium hypochlorite supplementing. Sufficient chlorine was used to maintain a tested residual of 0.1 to 0.5 p.p.m. in the tank effluent. The only completed part of the plant at that time being the pumps and clarifiers, chemical feeding was necessarily on an emergency basis and operating data are excusably incomplete. No figures are available for July, but the remaining months are comprised in Table I. The laboratory results by Mr. Carpenter covering the last six months of the year are shown in Table II.

The noteworthy point about Table II is that in spite of a settling period of some three hours the removals without the aid of precipitants averaged, for turbidity 13.6 per cent, for suspended solids 37 per cent, for settleable solids 65 per cent, for BOD 21 per cent. Staleness and comminution of the sewage partially explain these low results.

1936 Operation

Plain sedimentation was used during the first five months of 1936, as in the two preceding months of 1935. By the middle of June, it was

* Presented at the Ninth Annual Meeting of the New York State Sewage Works Association, New York City, January 22, 1937.

TABLE I.—*Principal Operating Data—1935*

Month	Est. Sewage Flow		Screenings Wet Lbs.			Sludge to Scow Cu. Ft.			Trips of Scow	Chlorine Fed Lbs.*		
	Month	Day	Month	Day	M.G.	Month	Day	M.G.		Month	Day	M.G.
August	513	16.5	18,900	610	37	87,000	2,810	170	8	22,149	714	43
September	582	19.4	15,150	505	26	47,500	1,580	82	4	23,535	785	40
October	529	17.1	10,400	336	19.6	51,500	1,660	97	5	20,436	658	38
November	542	18.1	9,600	320	17.6	54,800	1,830	101	5			
December	523	16.9	9,750	315	1.86	45,000	1,450	86	4			
Total	2,689		63,800			57.160			26	66,120		
Average	538	17.6	12,760	417	23,8	285,800	1,866	107	5.2	22,040	719	40

* Liquid chlorine—exclusive of hypochlorite.

TABLE II.—*Laboratory Data—1935 (Parts per Million)*

Month	Turbidity			Susp. Solids Total			Susp. Solids Volatile		Settleable Solids			5 Day B.O.D.			Sludge Per Cent Dry Solids
	Inf.	Eff.	%	Inf.	Eff.	%	Inf.	Eff.	Inf.	Eff.	%	Inf.	Eff.	%	
July	140	139	0.7	166	111	33	61	72	80	37	54	132	120	9	6.5
August	154	111	28	155	83	46	67	82	85	22	74	118	75	37	10.7
September	130	114	12	126	94	25	81	89	51	25	51	94	81	14	10.8
October	132	119	11	118	76	36	78	90	54	17	69	96	77	20	11.4
November	142	117	18	141	77	45	73	87	71	15	79	112	83	26	5.4
December	142	123	13	144	94	35	77	89	74	29	61	141	111	21	11.3
Average	140	121	13.6	142	89	36.7	72.8	84.8	69.2	24.2	65.0	115.6	91.2	21	9.4

apparent that delays in finishing the contract would prevent the use of the new chemical feeding equipment in time for the bathing season, and the decision was reached to resort again to temporary measures in order to secure the desired purification results. Accordingly, a temporary structure was erected over the wet well adjacent to the pumping station and equipped with a Wallace and Tiernan dry feeder with dissolving pots for ferric sulphate (Fig. 1). Also the chlorinators in the new chemical building were pressed into service using gaseous chlorine instead of liquid chlorine from the chlorine storage building, as contemplated.

Treatment of the sewage with ferric sulphate ("Ferrisul," supplied by Merrimac Chemical Co.) and chlorine ahead of the clarifiers was started June 20 and continued until October 7, 1936. Chlorine was then discontinued, but the ferric sulphate feed was continued until October 23d. During one week only of August, hydrated lime was experimentally used to test out equipment, with the other two chemicals men-

tioned. From September 1 until October 23, 1936, inclusive, hydrated lime was fed regularly.

The schedule may be summed up by saying that during the period June 20 to October 23, inclusive, 2,540 million gallons of sewage were treated with 325 tons of ferric sulphate (Ferrisul), 300 tons of hydrated

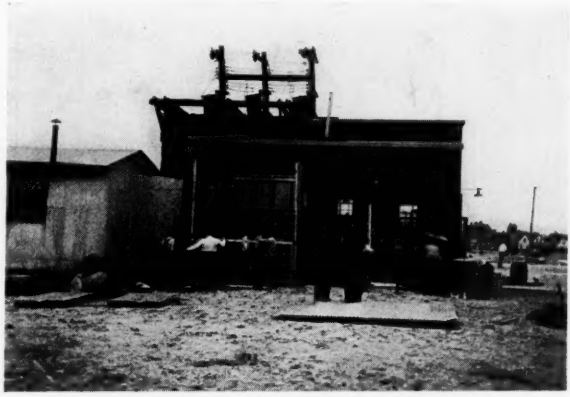


FIG. 1.—Temporary building erected over screen chamber to house "Ferrisul" feeder.

lime and 118 tons of chlorine in various combinations and dosages. The aggregate cost of these chemicals delivered to the plant storage was in round numbers $20,000. Labor and other charges for feeding chemicals to sewage are not included in this figure. The chemical data by months are shown in Table III, while the quantity and quality of materials removed from sewage are given in Table IV.

TABLE III.—*Chemicals Fed to Sewage—1936*

	Average Flow MGD	Chemicals Fed—Lbs.			Ave. Chem. Dose—Lbs./M.G.		
		"Ferrisul"	Hyd. Lime	Chlorine	"Ferrisul"	Hyd. Lime	Chlorine
June 20–30 incl.	19.5	41,920	—	19,300	202	—	100
July	21.1	155,430	—	68,310	238	—	104
August	20.7	169,200	43,970	69,710	264	Experimental	109
September	19.9	169,000	321,800	64,700	283	540	108
Oct. 1–3 incl.	19.7	116,170	233,880	14,230 (8 days only)	257	516	79
TOTAL		6651,720	599,650	236,250			
AVERAGE	20.2	5,170 (126 days)	9,995 (60 days)	2,130 (111 days)	261	528	100

NOTE: 3% of Ferrisul dose stated in Lbs./MG = Fe, as p.p.m. (Approx.)
8% of Hydrated Lime dose stated in Lbs./MG = CaO, as p.p.m. (Approx.)
12% of Chlorine dose stated in Lbs./MG = Cl_2, as p.p.m. (Approx.)

TABLE IV.—*Materials Removed from Sewage—1936*

Month	Ave. Flow MGD	Screenings Wet Lbs.		Raw Sludge						
				Tot. Cu. Ft.	Daily Cu. Ft.	Per Cent Solids	Dry Lbs.		Per Cent Volatile	Disposal
		Total	Daily				Total	Daily		
January	18.9	9,550	308	41,059	1,320	10.5	279,000	8,850		To sea
February	18.5	9,050	312	28,287	977	12.6	231,000	8,000		" "
March	20.4	10,200	330	46,917	1,510	13.2	405,000	13,050		" "
April	21.0	7,700	256	40,680	1,356	11.5	300,000	10,000	71.7	To sea and digesters
May	18.8	11,300	365	52,810	1,700	12.1	403,000	13,000	66.2	" " " "
June 1–19	18.5	6,500	342	33,140	1,740	12.4	261,000	13,700	62.7	To digesters
June 20–30	19.5	3,100	282	27,730	2,520	12.8	219,000	19,800	57.2	" "
July	21.1	9,100	294	118,580	3,825	12.2	883,000	28,470	64.0	" "
August	20.7	8,750	282	140,700	4,540	9.6	785,700	25,300	66.1	" "
September	19.9	8,000	267	109,970	3,670	8.6	517,900	17,260	60.9	" "
October	19.5	9,050	292	117,210	3,780	9.8	653,300	21,100	55.2	" "
November	17.3	9,900	330	34,140	1,138	11.1	241,600	8,050	63.9	" "
December	19.1	12,100	375	41,900	1,352	8.9	224,500	7,240	76.7	" "
TOTAL		114,300		833,120			5,404,000			
DAILY AVE.	19.5	314		2,280		11.2	14,800		64.5	

CHEMICAL HANDLING

Under the emergency conditions existing during the summer and fall, there was much annoyance connected with the feeding and handling of chemicals. Ferrisul was delivered to the plant by truck in 200 pound bags, stored in the bins of the chemical building, and taken from there by hand truck as required to serve the dry feed machine installed over the screen chamber. All Ferrisul was weighed as placed in the hopper of the dry feeder. With the make-shift dissolving pots some difficulty was experienced at times with solution although hot water was available.

FIG. 2.—First shipment of chlorine, 45 tons, arriving at Coney Island dock.

Chlorine was shipped by rail to Greenville Terminal, New Jersey, thence transferred by lighter in lots of 45, 30 and 15 tons to the Coney Island dock, from which it was placed in storage (Fig. 2). The chlorine evaporators in the chemical building not being functional at that time,

it was necessary to connect in the chlorine storage building a maximum of 12 one-ton cylinders to maintain adequate gas pressure to the chlorinators.

Hydrated lime was delivered to the chemical building by truck in 50

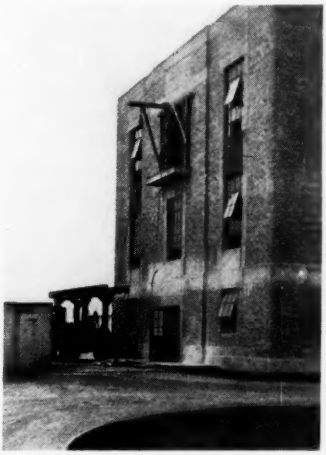


FIG. 3.—Temporary rig for hoisting lime to third floor of chemical building.

pound paper bags. Most of the lime was placed directly in the basement storage bin by the contractor. During most of the period when lime was fed to sewage, deliveries were made to the ground floor, then

FIG. 4.—Lime being received on third floor in chemical building.

hoisted by a motor vehicle hoist to the third floor of the chemical building, thence by hand labor to the daily supply hoppers (Fig. 3, Fig. 4). Electric power to the pneumatic chemical handling equipment was not available until the treatment season was practically over.

Treatment Results

Coney Island sewage in summer months is quite stale to the point of offensiveness. Approximately 13 per cent of the sewage reaching the station has been pumped twice already and 20 per cent has been pumped once, prior to being lifted by the Coney Island pumps to the sedimentation tanks. The 84 in. collecting sewer serving the plant permits sedimentation during the dry weather periods and is undoubtedly a material factor in the staleness of sewage as received at the station. Another complicating operating factor is the unusually wide variation in the contributing load by reason both of the shifting resident population to the beach areas during the warmer summer months, and the transient load on warm, fair week-ends at this very popular resort.

The laboratory data by Mr. Carpenter for the entire year are given in Table V and in simplified form by Fig. 5. In general, they show that

Table V.—*Laboratory Results—1936*

Month	Suspended Solids, P.P.M.			Settleable Solids, P.P.M.			B.O.D., P.P.M.			*B. coli* group, per c.c.		
	Inf.	Eff.	%	Inf.	Eff.	%	Inf.	Eff.	%	Inf.	Eff.	%
January	161	96	40	76	27	64	145	100	31			
February	169	100	41	75	23	69	197	132	33			
March	197	97	51	109	24	78	151	98	35	Not	reported	
April	183	93	49	100	22	78	147	89	39			
May	200	95	53	108	28	74	162	102	37			
June 1–9	186	95	49	104	25	76	128	91	29			
June 20–30	176	69	61	91	14	85	134	70	48	460,000	302	99.9
July	192	76	60	99	23	77	125	54	57	2,360,000	153	
August	178	64	51	99	16	84	113	52	54	890,000	171	99.9
September	186	55	71	115	16	86	110	49	55	2,400,000	483	99.9
Oct. 1–7	201	74	63	92	20	80	101	59	42	325,000	0	100
Oct. 8–23	189	73	61	113	23	80	127	62	51	5,400,000	540,000	90
Oct. 24–31	137	82	40	52	21	60	132	101	23	2,200,000	2,300,000	0
November	141	85	40	69	29	58	141	105	26	4,300,000	3,090,000	24
December	122	78	36	59	22	63	114	85	25	5,400,000	3,510,000	35
Average	174	82	51	91	22	74	135	83	39			

during the non-chemical months, January 1 to June 19 and from October 24 to December 31, the removal of suspended solids averaged about 44 per cent, while during the period June 20 to October 23, when using chemicals, the removal averaged 61 per cent. The 5-day B.O.D. removals during the corresponding periods were 31 and 51 per cent respectively. During these same periods, the removals of settleable solids averaged 69 and 82 per cent respectively.

Chlorine was applied to the raw sewage pump discharge line ahead of the sedimentation tanks, and following the Ferrisul application, which was at the wet well. An attempt was made to maintain a residual by ortho-tolidin test of 0.2 to 0.4 p.p.m. as sampled from the

rapid mixing flume, some 3 minutes after the point of application. No attempt was made to carry a residual through the settling tanks. The bacterial results shown in Table V indicate that the dose of chlorine averaging about 100 pounds per MG as applied in this manner, although insufficient to satisfy the chlorine demand, yet was quite effective for sterilization and at the same time provided, with the iron salt, complete nuisance control.

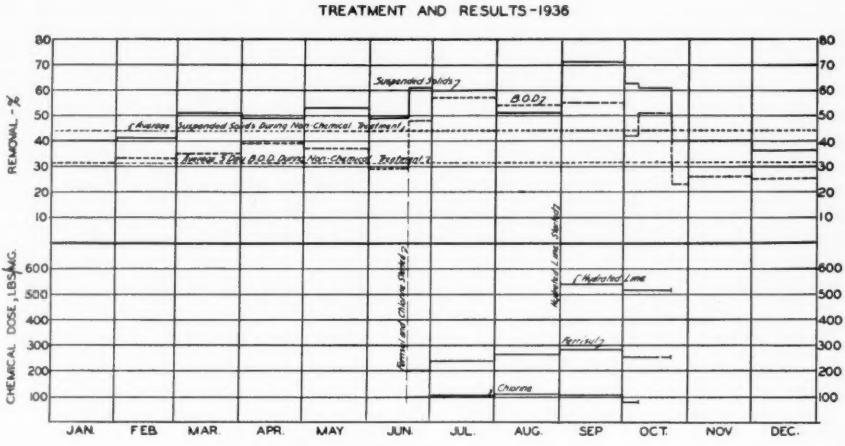


FIG. 5.—Per Cent Removals and Chemical Doses.

COST OF CHEMICAL TREATMENT

During 1936 the contracts for chemicals were as follows:

Ferrisul	300 tons, at $30.30,	delivered to plant.
Hydrated lime	500 tons, at $11.57,	delivered to plant.
Chlorine	120 tons, at $53.40,	delivered to tail terminus.

To the chlorine contract price must be added $9.00 per ton extra expense for lighterage from rail head to the plant, making the actual delivery price of chlorine at Coney Island $62.40 per ton, or 3.12 cents per pound. Additional Ferrisul was furnished under the construction contract.

On the basis of the unit prices indicated, the costs per million gallons of sewage treated for chemicals alone were:

	Per MG
June (11 days) Iron & Chlorine	$ 6.88
July (31 days) Iron & Chlorine	6.83
Aug. (31 days) Iron & Chlorine	7.77
Sept. (30 days) Iron, Lime & Chlorine	10.80
Oct. (6 days) Iron, Lime, Chlorine	9.55
Oct. (15 days) Iron & Lime	7.03

Disposal of Sludge

The disposal of raw sludge at sea in 1935 has been discussed briefly. Sea disposal was continued through the first five months of 1936 because the digesters were not ready for service. The quantities of raw sludge taken to sea, based on gaged volumes of the sludge scows and laboratory determinations of solids, are shown in Table VI. Since May 21, 1936, all raw sludge has been pumped to digesters.

Table VI.—*Trips of Sludge Scows to Sea—1936*

Date	Cu. Ft.	Wet Tons	Dry Tons
January 10	12,945	418	43.9
January 18	11,650	376	39.5
January 27	12,366	399	41.9
February 5	11,324	369	46.4
February 19	11,764	383	48.2
February 28	10,982	357	45.0
March 16	17,568	575	75.8
March 21	13,010	426	56.2
March 23	3,167	104	13.7
March 31	12,897	423	55.7
April 10	11,140	357	41.0
April 20	12,620	404	46.5
May 5	12,080	382	46.2
May 21	11,990	379	45.8
Total	165,503	5,352	645.8
Average	11,822	382	46.1

As barging of sewage sludge to sea is practiced by relatively few seaport cities in this country, chiefly Providence, R. I., the Passaic Valley Sewage Commission, N. J., and New Haven, Conn., some details of the Coney Island operation may be of interest. The Department has two wooden scows each equipped with six watertight bins or holds for transporting sludge. The general arrangement is indicated in Figure 6 and dimensions of the two scows are shown below:

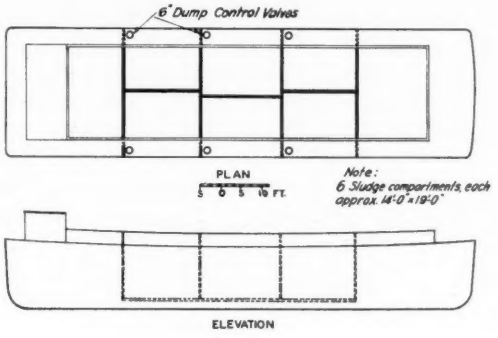
	Scow No. 1	*Scow No. 2*
Length	116 ft. 5 in.	114 ft. 7 in.
Beam	30 ft. 3 in.	28 ft. 8 in.
Light Draft	2 ft. 2 in.	2 ft. 2 in.
Load Draft	7 ft. 0 in.	7 ft. 0 in.
Dead Weight, tons	490	452
Displacement, Light, tons	198	195
Displacement, Load, tons	688	649
Sludge Cap'y, cu. ft., 8 ft. depth	13,900	12,570

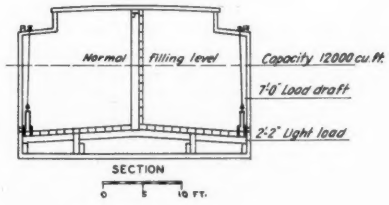
On account of shoal areas in Jamaica Bay, the cargo limit is about 12,000 cu. ft.

The dumping arrangement consists of a 6-inch gate valve in each of the six sludge compartments. These valves are located inside the sludge bins next to the outer shells of the vessels. The bin floors have

a slope from the center line outward so that the valves drain the holds. When loaded, the discharge valves are below the waterline but as the cargo is discharged, the valves are above the waterline. Each scow is equipped with a 4-inch centrifugal gasoline-driven pump for use in flushing the holds with sea water after dumping.

The scows are kept moored at the plant dock. They were filled by pumping at intervals through the day and night from the sludge pumping station to a stand pipe on the dock, from which the sludge was delivered through a 4-inch flexible hose connection to any of the six holds of the scow. The loaded scows were taken singly by a small tug to





SLUDGE SCOW

CONEY ISLAND SEWAGE TREATMENT WORKS

FIG. 6.—Scow used in transporting sludge.

Rockaway Inlet where a larger seagoing tug completed the round-trip to the authorized dumping grounds located 8 miles ESE of Scotland Light.

The contract price for towing was $210 per round-trip and the disposal operations included in Table VI represent a total of $5500 or $1.05 per wet ton of sludge, or $8.55 per dry ton of sewage solids. This sum included allowances for ice breaking and repair of vessels due to ice conditions, but does not include charges for Department personnel attached to the scows.

Due to the severity of the 1935–36 winter Shellbank Creek, on which the Coney Island plant is situated, became icebound and no sludge

vessels could be taken out for a period of several weeks. The digesters not yet being ready for service, it became necessary to cut one of the clarifiers out of service and use it as a storage tank for raw sludge pumped daily from the remaining three sedimentation units. Later this accumulation was barged to sea.

Disposal of Grease and Scum

Discharge of grease with sludge to sea not being permissible on account of objectionable effects on the waters, all material skimmed from the clarifiers since the plant was put in service, including 1936, has been pumped to sandy pits or beds adjacent to the clarifiers and there dewatered. In December, 1936, a start was made in removing the dewatered grease to one of the city incinerators for final disposal. Subsequent to January 1, 1937, grease has been partially dewatered by decantation in the receiving grease manholes and the more concentrated skimmings are now being pumped with the sludge to the digesters.

Disposal of Screenings

Material removed manually from the 1-inch opening bar screen has been hoisted in cans to the street level and sent to a city refuse incinerator. The new equipment includes a screenings grinder, but it has not as yet been put in service.

Digester Operation

The first digester was put in operation April 24, 1936, by filling with sewage effluent, warming up to about 70° F. and thereafter raw sludge was pumped in daily. Other digester units went into service between April 27 and August 25. Each of the 54-foot diameter digester units, at the filling levels used in practice, holds 56,000 cu. ft. of liquid. It will thus be seen that a total of 488,000 cu. ft. of digester capacity was available at the peak of the season. This should not be taken as a criterion of the digester capacity required under ordinary circumstances because the digesters went into service at the beginning of the summer load. As the summer load receded, two digester units have been withdrawn from service and others will be withdrawn for the purpose of determining the minimum capacity necessary to take care of the local conditions. The quantity and quality of digested sludge is given in Table VII.

No difficulties have been encountered in digester management, either with plain sludge or chemical sludge. The first digesters were started with lime to maintain an alkaline balance, but subsequent units were simply seeded from the first units and no lime used. Since heat has become freely available, digesters have been kept at a temperature approximating 83° F. Supernatant liquor from digesters has mainly been returned to the wet well of the sewage pumps, but it was found convenient to dewater a considerable portion on the sandy areas of the station grounds.

TABLE VII.—*Digested Sludge Data—1935*

Month	Cu. Ft. Drawn	Per Cent Solids	Total Dry Lbs.	Per Cent Volatile	Total Volatile, Lb.
August	27,100	9.6	161,500	48.7	78,700
September	32,480	7.2	145,400	51.2	74,500
October	12,670	9.2	75,000	45.2	33,900
November	26,000	11.3	183,000	40.6	74,300
December	39,550	10.5	252,600	43.7	110,500
TOTAL	137,800	·	817,500		371,900

DISPOSAL OF DIGESTED SLUDGE

During the period August 11 to the end of 1936, a total of 128,700 cu. ft. (or about 370 dry tons) of good quality digested sludge was withdrawn from the digesters by pumping to small lagoons or temporary drying beds on the sandy grounds of the station, for the purpose of preventing sand drifting and to prepare these areas for planting grass next spring. A substantial part of the sludge pumped has become dewatered to a cake, and this cake has been broken up and mixed with the sand to make top soil. The remaining areas will be similarly treated as weather permits.

FIG. 7.—Discharge of digested sludge on sand beds at Marine Park.

An interesting phase of the disposal of digested sludge was the transfer in December of a scowload of digested sludge from Coney Island by water to Marine Park and the discharge of this cargo amounting to 9,100 cu. ft. averaging 11.7 per cent dry solids and 43.3 per cent volatile (Fig. 7). This is the equivalent of 300 wet tons or 36 dry tons. This sludge will lie on the sand beds at Marine Park until next spring when use will be made of it in developing this extensive new municipal park. The cost of towing the scow to Marine Park was $100 or $2.80

per dry ton of sewage solids. Department personnel carried out the operations of pumping the sludge from the scow to beds prepared by the Park Department.

The ultimate disposal of digested sludge as contemplated will be dewatering by vacuum filter and utilization of the sludge cake as a soil conditioner, both on the station grounds and on city parks. To date the vacuum filter equipment has not been ready for service and no sludge has been dewatered in this manner.

Gas Production and Utilization

A satisfactory record of digester gas quantities is not available because of the early lack of metering facilities. A temporary gas meter was used during initial stages of digestion but when the capacity of this meter (50,000 cu. ft.) was topped, no reckoning was available except by special displacement tests of the individual gas holders. It is known that toward the end of July, the gas production approximated 300,000 cu. ft. daily. After the gas engines were put in service and the orifice gas meter supplying these engines became available, accurate figures for gas became possible, provided gas production does not greatly exceed metered uses, in which case there is an undetermined loss. The principal use of the gas is for the engines, referred to below. The quality of digester gas is shown by analysis in Table VIII. No calorimetric data have been taken.

Table VIII.—*Gas Consumption and Engine Performance—1936*

Month	Gas to Engines—Cu. Ft.		Power—KWH		Cu. Ft. Gas per KWH	Gas Per Cent CO_2
	Purchased	Digester	Purchased	Generated		
January			117,350			
February			104,630			
March			126,320			
April			126,400			
May			116,400			
June			113,600			31.1
July			135,600			33.8
August			144,800			31.8
September		No meter	111,200	10,500	No meter	31.1
October	4,800	No meter	30,000	86,970	No meter	30.6
November	356,000	No meter	300	90,670	No meter	33.1
December	0	2,522,720	0	109,760	23.0	33.6
Total			1,126,600	297,900		
Average						32.2

Power Production

The first of the three Worthington 300 H.P. gas engines was put in service September 4th. As the units were tuned up and the electrical work was completed, a greater proportion of the power load of the

plant was taken over by the plant generating units. Since November 1st, the entire power load has been carried by the station generators and connection with the utility company is now discontinued. The electric energy so generated is used to pump all sewage at the station and to operate various motors of the plant. Table VIII shows the energy production since the engines were started with the net gas supplied the engines, both from utility gas and digester gas. The utility gas has a B.T.U. value of 540 per cu. ft. while the computed B.T.U. value of digester gas is 650 per cu. ft. The engines are guaranteed to develop 1 BHP hr. from 9,500 B.T.U. supplied, at full load. During December there was generated an average of 3,541 KWH per day using an average of 81,378 cu. ft. of digester gas, or 23.0 cu. ft. of gas per KWH generated.

Conclusion

It would be unwise to draw too fine conclusions from the data and experiences presented above, for it is obvious that the 1936 operations were carried out under emergency conditions, with a partly finished plant, which imposed limitations on the maximum dose of precipitating chemicals, the most desirable sequence and combinations of chemicals and their accurate regulation in accordance with the sewage load. Neither were the flocculators available during most of the period. However, the main objectives of treatment have been fairly met, namely substantial clarification and disinfection of the effluent prior to discharge to tidal dilution, thus affording protection to coastal bathing areas.

Publications Relating to Coney Island Plant

Richard H. Gould, "The Proposed Coney Island Sewage Treatment Works of New York City," *Waterworks and Sewerage*, **82**, 53 (Feb., 1935).

Richard H. Gould, "Sewage Disposal in the City of New York," *Civ. Eng.*, **5**, 158 (March, 1935).

Anonymous, "Treating Coney Island's Sewage," *Eng. News Record*, **115**, 489 (Oct. 10, 1935).

Walter D. Binger and Richard H. Gould, "Sewage Treatment in New York City," *Civ. Eng.*, **6**, 789 (Dec., 1936).

DESIGN OF THE SEWAGE TREATMENT WORKS OF THE SANITARY DISTRICT OF CHICAGO*

By L. C. Whittemore and Norval E. Anderson

Engineer of Design and Engineer of Treatment Plant Design

Construction of the Southwest Sewage Treatment Works—the last of the Sanitary District's four major treatment projects—is well under way. With the completion of this plant and the various intercepting sewers now under construction sometime during 1938, over 97 per cent of the human sewage and substantially all of the industrial wastes originating within the boundaries of the Sanitary District will be given some form of treatment—complete by the activated sludge process at the North Side, Southwest and Calumet Works, and partial by settling in Imhoff tanks at the West Side Works. The general characteristics of the four major treatment works are indicated in the following table:

Treatment Works	Type of Treatment	Design Capacity, Average, Mil. Gals. Daily	Design Population, Human	Construction Started	Operation Started
North Side	Activated Sludge	175	800,000	1923	1928
West Side	Imhoff Tanks	467	1,850,000	1926	1930
Calumet (New)	Activated Sludge	136	455,000	1931	1935
Southwest	Activated Sludge	400	1,300,000	1935	—
Total		1,178	4,405,000		

In addition to the human population, the Southwest Works will also provide treatment for the wastes from Packingtown, roughly equivalent in strength to the sewage from 1,000,000 persons. The West and Southwest Works, while listed as separate projects, are located adjacent to each other on the same site and will be operated as component parts of one large plant.

All of the Sanitary District plants are designed to treat maximum flows up to 150 per cent of average. To collect and convey this large volume of sewage to the various works for treatment has involved the construction of approximately 156 miles of intercepting sewers in varying sizes up to 17 ft. 3 in. by 19 ft. 2 in. and built largely in tunnel. To dispose of the large quantity of waste solids accumulated in the process of treatment, sludge disposal facilities for a total estimated average load of approximately 550 tons of dry solids per day are provided. The West Side solids are digested in Imhoff tanks, air dried on sand beds and the dried residue disposed of by dumping on waste land along

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the Main Channel. For the Calumet and Southwest Works, mechanical dewatering followed by heat drying and incineration has been adopted. The North Side waste sludge is pumped to the West-Southwest site, where part is digested in the Imhoff tanks while the remainder will be handled with the Southwest sludge in the dewatering and incineration plant.

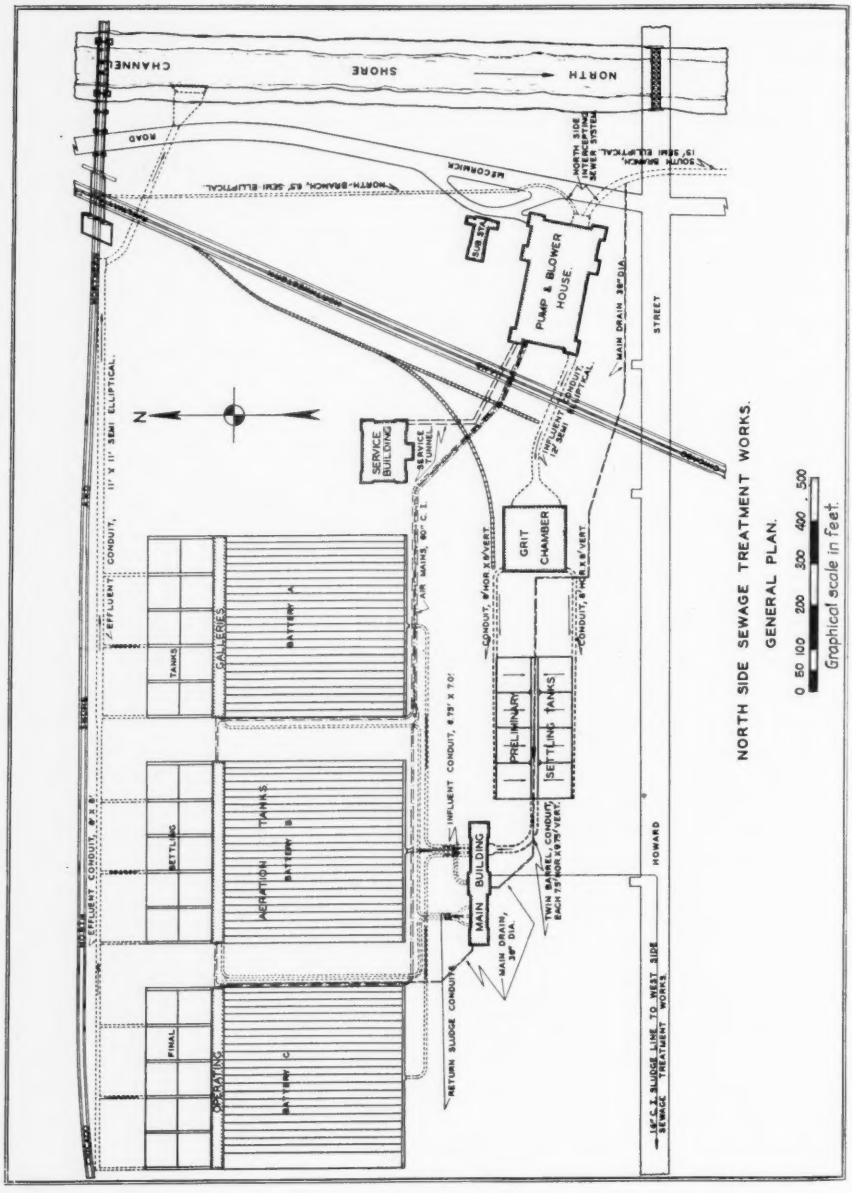
In addition to the works listed above the Sanitary District, prior to the construction of the North Side Works, built, operated, and later abandoned in 1931, for reasons of operating economy, a 4.5 m.g.d. semi-experimental activated sludge plant for a group of suburban communities along the Des Plaines River, since made tributary to the West-Southwest Works, and also an Imhoff plant with a number of added experimental features, which has only recently been replaced by the new Calumet Works. Both of these plants served a useful purpose in providing treatment over a period of years and perhaps a more useful function in serving as large scale testing stations and laboratories for the development of improved methods for the Sanitary District's larger and later works.

In this paper we shall attempt to trace briefly some of the developments which have taken place in the design of successive plants, in a general way, rather than to attempt a detailed description of all the works of the Sanitary District.

Preliminary Treatment

It was originally intended to precede the aeration process at the North Side Works by fine screening through mechanically cleaned units with openings $\frac{1}{16}$ inch in width. Comparative studies indicated, however, that much more treatment could be accomplished for the same or less cost with a brief period of preliminary sedimentation, and tanks for this purpose with a detention period of 30 minutes at average flow were accordingly substituted. While subsequent observation has indicated that very little economy in air use is accomplished by preliminary sedimentation under Chicago conditions, these tanks serve a very useful purpose in smoothing out the effects of peak solids loads during storms and retaining some of the heavier and coarser solids which otherwise tend to become stranded in the aeration system. Their use is justified for these reasons alone. Further, with the development of mechanical dewatering of sludge by vacuum filtration (to be discussed later) it appears that the addition of 15 to 20 per cent of fresh solids by weight to activated sludge adds materially to the rate and economy of filtration. Accordingly, preliminary sedimentation has also been provided both at the Calumet, and Southwest Works, with detention periods at average flow of 10 and 34 minutes, respectively.

The North Side preliminary tanks are preceded by rack screens and grit chambers. With the adoption of mechanical dewatering and incineration for the Calumet and Southwest Works, it was felt that there was no particular need for separating the grit from the other sewage solids. Grit chambers have not yet been provided for either of these plants, the grit being removed in the preliminary tanks along with the


NORTH
SHORE
CHANNEL
ROAD
NORTH SIDE INTERCEPTING SEWER SYSTEM
SOUTH BRANCH, 15' SEMI ELLIPTICAL
NORTH BRANCH, 13' SEMI ELLIPTICAL
McCORMICK
PUMP & BLOWER HOUSE
MAIN DRAIN 36" DIA.
STREET
HOWARD
SERVICE BUILDING
SERVICE TUNNEL
AIR MAINS, 60" C.I.
GRIT CHAMBER
PRELIMINARY SETTLING TANKS
INFLUENT CONDUIT, 6'9" X 7'0"
TWIN BARREL CONDUITS, EACH 7'9" HOR. X 6'9" VERT.
MAIN BUILDING
MAIN DRAIN, 36" DIA.
RETURN SLUDGE CONDUITS
16" C.I. SLUDGE LINE TO WEST SIDE SEWAGE TREATMENT WORKS
AERATION TANKS
BATTERY A
BATTERY B
BATTERY C
GALLERIES
TANKS
SETTLING
FINAL
SPRAYING
EFFLUENT CONDUIT, 11' X 11' SEMI ELLIPTICAL
EFFLUENT CONDUIT, 9'6" X 9'6"
N
NORTH SIDE SEWAGE TREATMENT WORKS.
GENERAL PLAN.
0 50 100 200 300 400 500
Graphical scale in Feet.

coarser organic solids. As rather elaborate provision is being made for skimming of the preliminary tanks at the Southwest Works on account of the presence of the wastes from Packingtown, with high grease content, no fine rack screens are included, it being assumed that the material ordinarily removed by such screens will either sink in the preliminary tanks as sludge or be retained as scum. Neither screens nor grit chambers accomplish much in the way of treatment, are relatively costly structures to build and operate, and are useful principally as protective devices to other parts of the plant. Furthermore, each produces a separate increment of solids which must be handled in some manner. If these structures can be eliminated, and we believe that they can under the conditions of operation noted, a considerable saving both in first and annual costs will result. However, to be on the safe side, the Calumet Works are so laid out that grit chambers may be easily added in the future, if found necessary. Similarly, the Southwest Works are so arranged that either rack screens, or grit chambers, or both, may be readily built if needed. Coarse rack screens are used ahead of the sewage pumps in all plants for protection of pumping equipment.

At the West Side Works, preliminary tanks, with detention of 15 minutes at average flow, are also used, but for a different purpose—namely, to provide for skimming and to concentrate the grit. The combined grit and coarser organic solids which are deposited are withdrawn as a concentrated underflow, and the grit separated from the organic solids in one or two grit chambers only of ordinary type. If the preliminary tanks for grit concentration had not been used, it would have been necessary to have a much larger number of grit chambers than the four actually provided and no facilities for skimming would have been available ahead of the Imhoff tanks. The effluent from the grit chambers is returned to the preliminary tank effluent and both passed along to the Imhoff tanks for settling.

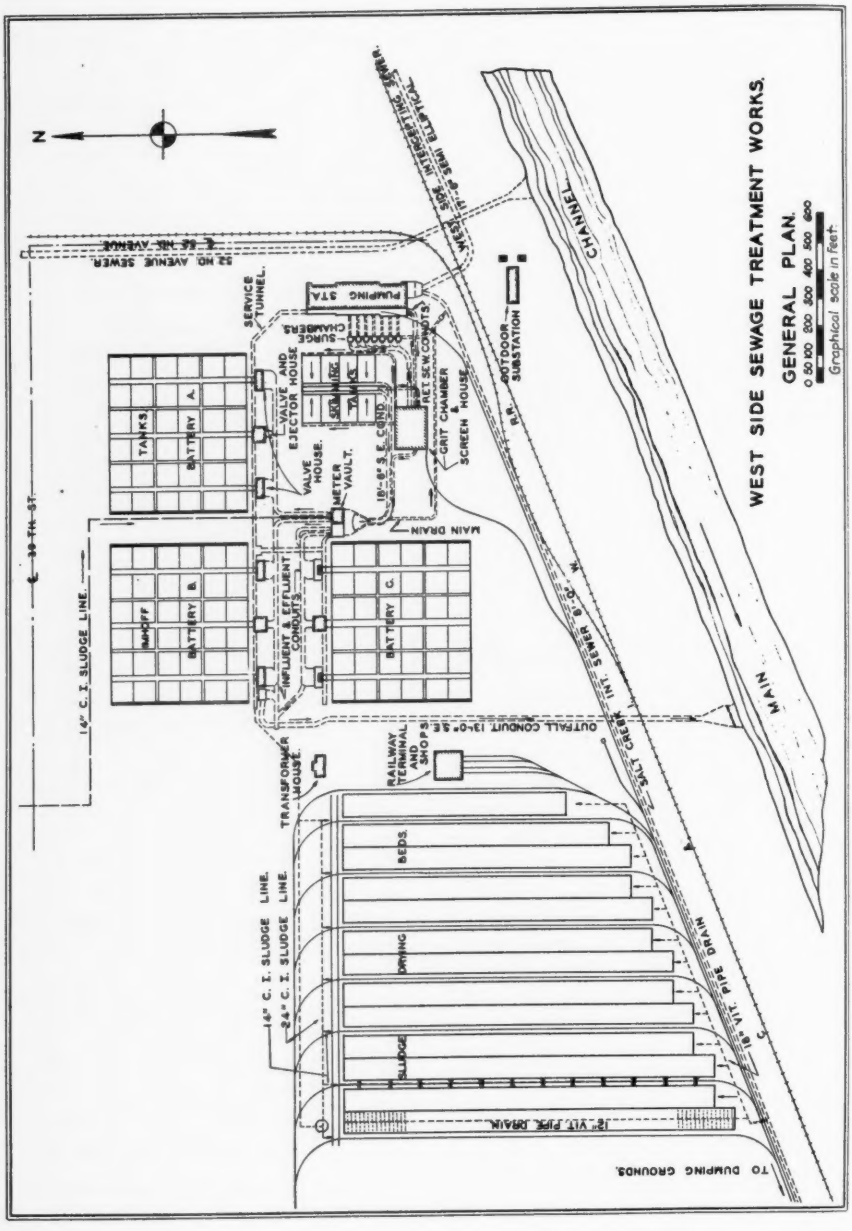
Aeration System

In order to illustrate some of the changes which have been made in the design of aeration tanks for the activated sludge process, the following table, showing some of the design factors, is introduced:

Design Bases for Aeration Tanks of Major Activated Sludge Plants

	North Side	Calumet (New)	Southwest
Design flow, average, mil. gals. per day	175	136	400
Number of aeration tanks	36	21	16
Number of aeration channels	71	21	64*
Channel width, ft.	16.12	33.16	32.75
Channel length, ft.	420	425.5	1736*
Water depth, over plates, ft.	15	15	15
Rows diffuser plates per channel	2	2	2
Diffuser plate ratio	1 to 9.4	1 to 19.5	1 to 20.2
Aeration period, average flow, hrs.	6.25	5.0	5.0
Free air, cu. ft. per gal. of sewage	0.8	0.5	0.5

* Four passes per tank in series, forming one continuous channel.


WEST SIDE SEWAGE TREATMENT WORKS.
GENERAL PLAN.
Graphical scale in feet.
N
CHANNEL
MAIN
SERVICE TUNNEL
PUMPING STA.
VALVE HOUSE AND EJECTOR HOUSE
SURGE CHAMBERS
TANKS
BATTERY A.
BATTERY B.
BATTERY C.
RUNOFF
VALVE HOUSE.
METER VAULT.
GRIT CHAMBER
SCREEN HOUSE
OUTDOOR SUBSTATION
MAIN DRAIN
INFLUENT & EFFLUENT CONDUITS
OUTFALL CONDUIT
INT. SEWER
SALT CREEK
RAILWAY TERMINAL AND SHOPS
TRANSFORMER HOUSE
BEDS
DRYING
SLUDGE
TO DUMPING GROUNDS
14" C. I. SLUDGE LINE.
24" C. I. SLUDGE LINE.
12" V.I.T. PIPE DRAIN
18" V.I.T. PIPE DRAIN

Examination of this table shows that some factors have remained unchanged, while others have undergone marked changes.

Preliminary plans for the North Side tanks contemplated the ridge and furrow system of aeration, following the design of the Des Plaines tanks, but experiments in one of our smaller testing stations quickly demonstrated the superiority of the spiral flow system with diffuser plates arranged along one side of the tanks. The design for the North Side Works was changed to spiral flow before construction started and this system has been used in all the Sanitary District's later works. Its retention calls for little comment, as it has been adopted almost universally in air-diffusion plants built in recent years.

It will be noted that the water depth has remained unchanged, but that important changes have been made in the width and length of the aeration channels. In the Des Plaines River plant, channels both 10 and 15 feet in depth were used. Early operation showed little difference in efficiency between the two depths, but comparative studies indicated an appreciable difference in cost, particularly for plants of large size, in favor of the 15-foot depth. Some theoretical studies which we have made have indicated that a still greater tank depth might possibly be used to advantage. As comparative experiments with tanks of greater depths on a scale of sufficient magnitude to be conclusive would be expensive in both money and time, and as the possible indicated savings are not large, the Sanitary District has adhered to the 15-foot depth.

In the North Side Works, the aeration channels are arranged in pairs with a non-pressure wall between, forming 36 tank units separated by pressure bearing walls. In one of the 36 tanks, however, the dividing wall was left out, forming a channel 33.5 feet wide. This channel was equipped with four rows of diffuser plates, thus maintaining approximately the same plate ratio as in the other channels. It was found that a channel of this width could be operated to produce an effluent of the same quality and with the same volume of air per gallon of sewage as one of half the width. In the design of the Calumet Works, the width of the aeration channels was accordingly doubled. The economy in use of concrete and reinforcing steel with increased width of channels is obvious. For further economy, alternate channel walls at the Calumet Works were made non-pressure bearing. The idea has been extended at the Southwest Works, where each tank unit consists of four passes in series, three out of four walls being non-pressure bearing. In addition to economy in use of concrete and reinforcement with this type of construction, further important savings accrue in cost of controlling equipment with decrease in number of tank units. It is possible that still wider channels may be safely used, and experiments along this line are now under way at the Calumet Works where a dividing wall was omitted between two adjacent units, making one channel 67.5 feet wide.

It will be observed that the diffuser plate ratio has been greatly reduced in the later designs. It has already been noted that the double

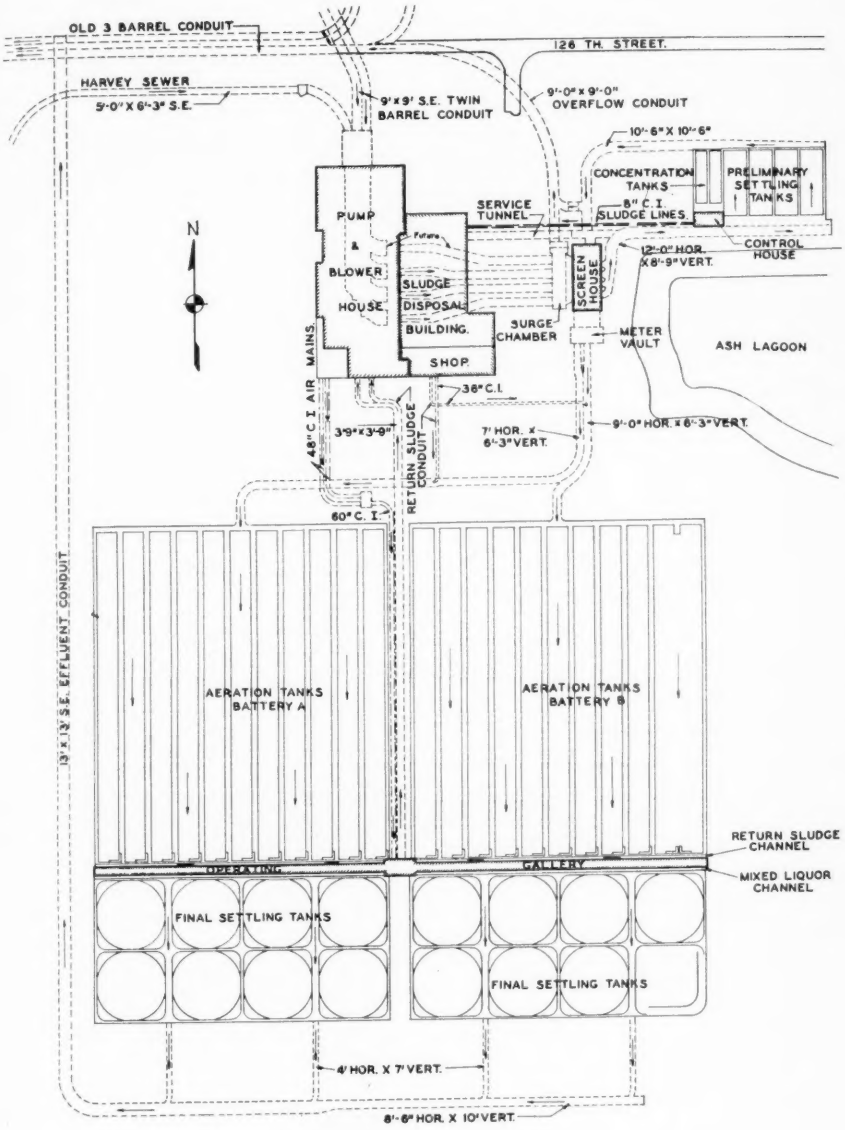
width channel at the North Side was equipped with four rows of plates. It was found after careful experiment that two rows were adequate for a tank of this width, and accordingly the plate ratio for both the Calumet and Southwest Works has been made but half that at the North Side. Actually one row of plates has operated successfully in the double width channel at the North Side and some of the Calumet tanks have been equipped with but one row of plates although containers for two rows were installed. While it may be entirely feasible to operate with but one row of diffusers, in channels 33 feet wide, considerations of relative air pressure losses and a reasonable factor of safety have led us to provide two rows of plates per channel.

When the North Side aeration tanks were being designed it was thought that a shorter detention period than the 6¼ hours provided might be feasible, and the plant hydraulics were so arranged that average and maximum flows could be increased by as much as 40 per cent. Because of the unusually rapid population growth on the North Side area during the 1920–30 decade (1930 population 977,000), this plant started with an average sewage flow of about 200 m.g.d., which was considerably in excess of its design capacity. It successfully carried the load, however, with an average detention period of about 5 hours. When the Calumet plant was designed, the aeration detention period at average flow was accordingly cut down to 5 hours and the same period was used for the Southwest Works.

Experiments at the North Side Works during the last two years have indicated that the aeration period may be still further reduced, one of the three batteries having been operated continuously on a detention period of from 3 to 3½ hours, with no appreciable sacrifice in air economy or quality of effluent. It is expected that advantage will be taken of this possibility at the new Southwest Works by operating the aeration plant continuously at a rate materially higher than its average design rate and taking excess storm flows through the West Side Imhoff tanks for settling only. In this way the maximum of treatment will be obtained with the facilities available and the West and Southwest Works are so interconnected that this flexibility of operation is possible.

When design of the North Side Works was started, an allowance of 1.25 cu. ft. of free air per gallon of sewage was made. With the adoption of spiral-flow aeration this allowance was cut to 1.0 cu. ft. as experiments had indicated some air economy over ridge-and-furrow aeration. With the substitution of preliminary settling for fine screening, with consequent removal of the coarser organic solids, the estimate was further cut to 0.8 cu. ft. per gallon. Actual operation on a careful basis of control has shown that it is possible to secure consistently good results with about 0.4 cu. ft. per gallon.

Less change has been made in the design of final settling tanks than in the aeration tanks. Larger tank units have been used in the later designs and better arrangements for uniform distribution of flow to the various tanks have been provided. At all plants mechanical equip-



CALUMET SEWAGE TREATMENT WORKS
GENERAL PLAN

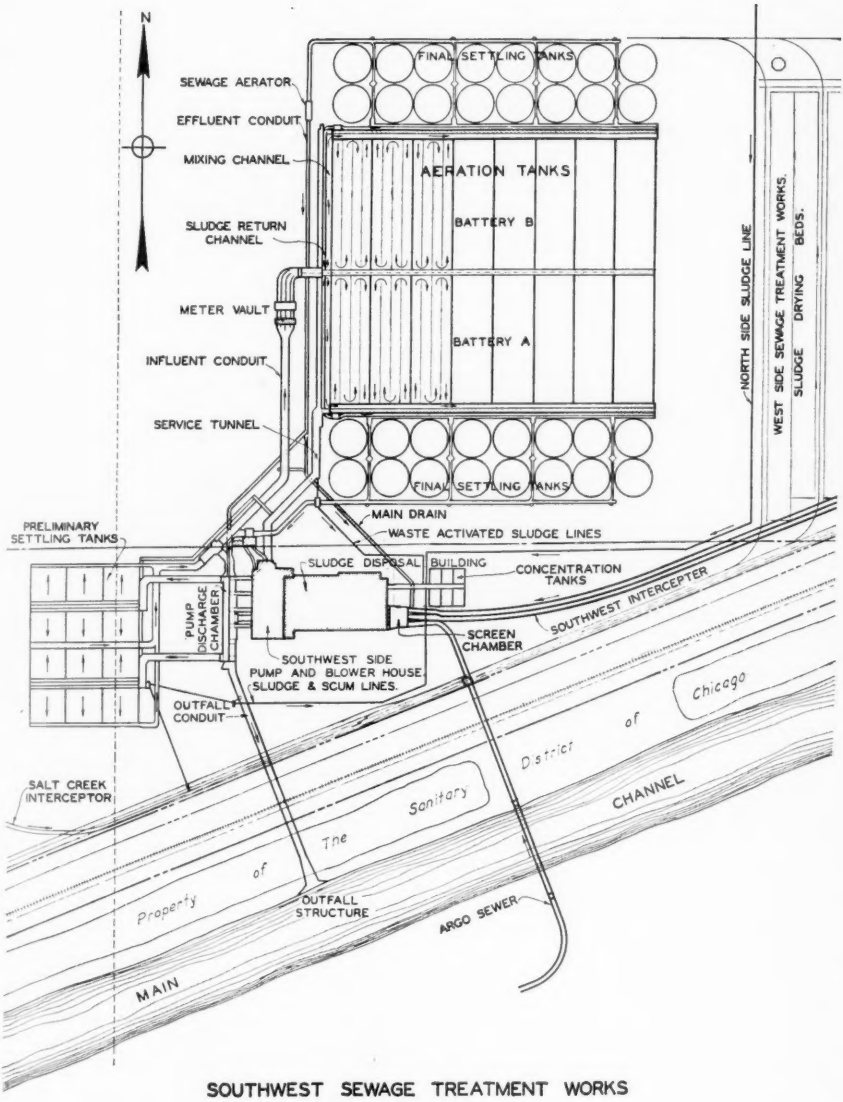
0 50 100 200 300 400

Graphical scale in feet.

ment for the removal of sludge has been employed. There have been many improvements made in such equipment in recent years over what was available when the North Side Works were built. The North Side final tanks have been operated continuously at rates somewhat in excess of the design rate of 1,200 gallons of mixed liquor per square foot per day with consistently good results.

One of the most novel features in the design of the aeration system for the Southwest Works is the use of air lifts in place of pumps for returning sludge. While air lifts have been employed before for this purpose in plants of small size, including the Sanitary District's Des Plaines River Works, their use on a scale approaching that of the Southwest Works, with a total sludge return capacity of 160 million gallons daily, has never been attempted before, so far as we know. The underlying factors leading to their adoption were the cost and difficulty of getting the very large sludge return conduits in and out of a common pumping station and the practical impossibility of getting efficient pumping units to handle the widely varying flows at the low heads required. No data were available on air lifts with the requisite characteristics, of large capacity at low heads. Accordingly, an exhaustive series of tests was made on lifts up to 18 inches in diameter, and at heads up to 5 feet, in order to determine the design constants. As finally laid out, two 16-inch lifts are provided for each final settling tank—one for ordinary sludge flows and the second as a supplement for high flows. It is eventually expected to make the withdrawal of sludge from individual tank units largely automatic and to maintain a fixed and predetermined sludge blanket level in each unit, by means of photo-electric cell controls in the air valves controlling the supply to the lifts. Enough experimental work has already been done along these lines to indicate that the idea is feasible.

Another unusual feature in the design of the Southwest Works is the special provision made for aeration of the final effluent. It has been observed in the Sanitary District's various plants, and particularly at the North Side Works, that wherever there is a drop or fall in an effluent conduit, causing agitation, there is a substantial increase in dissolved oxygen. Three such falls occur in the effluent conduits and channels at the North Side Works and, as a result, the final effluent, as discharged into the North Shore Channel, carries a dissolved oxygen saturation value of 80 to 85 per cent the year round. This dissolved oxygen is, of course, valuable to satisfy some of the residual B.O.D. of the final effluent. Small scale experiments indicated that, within limits, the oxygen absorption is roughly proportional to the height of fall. At the Southwest Works, some surplus fall is available between the final settling tanks and the Main Channel. To use this surplus head most effectively in promoting the absorption of dissolved oxygen, an aeration chamber has been built for that portion of the plant effluent not used for condenser water. This aeration chamber, in brief, consists of a long overfall weir chamber which concentrates the available drop at one point.



SOUTHWEST SEWAGE TREATMENT WORKS

GENERAL PLAN

0 50 100 200 300 400 500

Graphical scale in feet.

Sludge Handling and Disposal

During the preliminary stage of planning for the North Side Works, only two methods of disposing of waste activated sludge appeared feasible, namely,—(1) filtering and drying as a fertilizer base, and (2) pumping to land areas along the Main Channel through a force main approximately 18 miles long, and lagooning. The former method had been tried on a small scale at the Des Plaines River plant and at the experimental activated sludge units of the old Calumet Works, but comparative studies indicated that it would be unduly costly for the North Side Works. Lagooning was decided on as a temporary expedient, pending the development of a more satisfactory method.

Before it became time to provide for disposal of the waste sludge from the North Side Works, a series of experiments on the digestion of activated sludge mixed with fresh solids in the old Calumet Imhoff tanks had proved so successful that the earlier idea of lagooning was abandoned. Instead, it was decided to provide for digestion of the North Side solids at the West Side Works, with the fresh solids settled out in the Imhoff tanks.

This decision made necessary one of what are perhaps the two unusual features of the West Side Works, aside from their great size, namely the unusually large amount of digestion space allowed in the Imhoff tanks. This plant consists of 108 Imhoff tanks, each 80 feet square, divided into three batteries of 36 units each. The Calumet experiments had indicated that a wetter sludge would be produced in digesting a mixture of fresh and activated solids than with fresh solids alone. On account of this fact and to make due allowance for the greater removal of suspended solids in the activated sludge process than by plain settling, the first two batteries were designed with a sludge digestion volume of 2 cu. ft. per capita for the fresh solids settled out from the West Side sewage and 5 cu. ft. per capita for the waste activated solids from the North Side Works. After the first two batteries were placed in operation, it was found that this allowance was inadequate, the moisture content of the combined sludge in the digestion compartments being appreciably higher than that produced at the Calumet Works under similar conditions. The third battery was accordingly designed with larger sludge digestion volume than the preceding two, the total for the three batteries being some 10,530,000 cu. ft. Even with the addition made to the digestion capacity of the third battery, it was realized that a still further increase would be required when the plant was brought up to its full working capacity.

The other unusual feature of the West Side Works is the mechanical cleaning of the sludge drying beds, made almost necessary by reason of the very large volume of material to be handled. Two automatic cleaning machines, each capable of removing approximately 4½ cu. yds. of dried sludge per minute from beds 80 feet wide and 800 to 1400 ft. long, are in use. One of these machines was developed by the District's engineers while outside consulting service was employed for the design of the other.

To ascertain whether separate digestion of sludge, controlled in heated tanks, would give any better results than Imhoff tank digestion, experiments using mixed fresh and activated solids were carried on for a year in 1931–1932 at the West Side in two heated units of combined capacity of 700,000 gallons. No substantial improvement in moisture content over that obtained in the Imhoff tanks was found. In view of the large amount of digestion capacity which was found necessary for mixtures of fresh and activated solids, development was started on the idea of sludge disposal by means of mechanical dewatering, heat drying, and subsequent incineration.

In the summer of 1932, an experimental unit with capacity of 20 tons of dry solids per day was placed in operation at the West Side, including a vacuum filter followed by a combined drying and incinerating unit. The filter, operating on sludge conditioned with a coagulant, produced a cake of 75 to 80 per cent moisture. The dryer was of the direct-indirect type, with a rotating steel drum 8 feet in diameter and 70 feet long with an inner heating tube. The sludge was mixed with returned dried sludge, producing a mixture of about 50 per cent moisture. This mixture was dried to a moisture content of about 10 per cent. The dried sludge was then fed to the furnace with the small amount of coal which was necessary to support combustion. An inert mineral ash resulted. While it was found possible to dry and incinerate the sludge, considerable difficulty was experienced in controlling the drying cycle to produce an end product of reasonably uniform moisture content. Some little trouble with release of odors was also encountered. In the meantime additional experiments were started on "flash" drying in a hammer mill and the preliminary tests indicated that control with this method of drying would be more certain.

The experimental plant was accordingly modified by providing a two-stage "flash drying" unit in place of the rotary dryer. In this unit the mixed solids were dried in about 1.5 minutes instead of the 90 minutes required in the rotary dryer. Furthermore, by heating all gases up to 1400 deg. Fahr. or more, all odors were burned out. The heat was recovered by means of heat-transfer apparatus. Superheated vapor was found to be a more effective drying medium than air.

When construction of the new activated sludge plant for the Calumet Works was started in 1931, the decision on the method of sludge disposal was postponed until the various experiments and economic studies were completed. Three methods appeared feasible, namely:

(1) Digestion in Imhoff tanks and outdoor drying on sand beds.
(2) Separate digestion in heated tanks and outdoor drying on sand beds.
(3) Mechanical dewatering followed by heat drying and incineration.

Critical studies of the three methods, including some variations on each, clearly indicated that the third method was the most economical both in first and operating costs, despite the fact that new construction throughout was figured on for the third method while for the first two, use of the existing Imhoff tanks was contemplated as far as available

but no charge for these tanks was included in the estimates. Aside from the economy of the process, the end product is an inert ash of much less bulk than the dried sludge from the sand beds.

Mechanical dewatering, with heat drying and incineration, was accordingly adopted for the new Calumet Works, with an initial installation to handle 40 tons of dry solids per day. This plant has now been in operation for several months. While certain mechanical difficulties developed which are being readily corrected, the basic principles involved have worked out entirely as expected. The process has accordingly been adopted for the Southwest Works also and the latter plant will have a maximum capacity of 487 tons of dry solids per day, sufficient not only for the waste sludge from the Southwest area but also for most of that from the North Side Works. For the time being at least, digested sludge from the West Side Works will continue to be dried on sand beds.

The process, as finally developed, is as follows:

The first step in the process consists of tank concentration followed by mechanical dewatering of the sludge on vacuum filters, reducing the moisture from 97–98 per cent down to 75 to 80 per cent. Prior to filtration, the sludge is conditioned by the addition of ferric chloride to the extent of approximately 5 per cent by dry weight of sewage solids. The cake is then mixed with predried sludge, making a mixture of about 50 per cent moisture, and then dried by the flash method, in a totally enclosed system, by contact with continuously recirculated vapor, from the sludge, superheated to a temperature of approximately 1000 deg. Fahr. Excess vapor from the drying system and other gases are passed through the furnaces and subjected to a temperature of at least 1400 deg. Fahr., to destroy all odors before release to the atmosphere. Heat carried in the products of combustion and the deodorized vapors are passed through a high temperature heat exchanger for transfer to the vapor circulating in the drying system. Heat balance studies indicate that sludge containing 7,500 B.T.U. per lb. dry will furnish sufficient heat to evaporate moisture from the filter cake entering the drying system at 80 per cent moisture. The dried sludge, usually below 10 per cent moisture, is blown into the furnace and burned in the presence of preheated air. Powdered coal is also blown in through a separate nozzle as necessary. At Calumet, which is a comparatively small installation, oil burners are being installed to obtain greater flexibility. All products of combustion are passed through a Cottrell dust precipitator before release to atmosphere. It is estimated that about 80 per cent of the total ash will be recovered in the dust precipitators in the form of fly ash, and the remainder in the furnace bottoms in granular form free from clinker. All ash will be disposed of by dumping. The drying system is so arranged that dried sludge may be removed from the system instead of being fed to the furnaces, if it proves desirable to sell this material as a fertilizer.

The adoption of dewatering and incineration of waste sludge for the Southwest Works has led to another interesting development at

that plant, namely, the use of steam turbine driven main units instead of the electric drives used at the other plants. The steam turbine driven units include the main sewage pumps, blowers for supplying compressed air for aeration, and generators for supplying electrical energy to electrically driven auxiliaries. The use of steam is made economical by reason of the fact that steam generation can be combined with sludge incineration at a relatively small additional cost over the cost of incineration alone, and plant effluent can be used for condensing water without additional pumping, owing to the available head between the final settling tanks and the Main Channel. Little or no additional labor will be required over the requirements for all electric operation, and the annual cost for power will consist largely of the cost of coal for producing steam and the fixed charges on the additional boiler equipment.

General Design

In the general design and layout of the Sanitary District's plants, there has been a transition toward simplicity and compactness. This has been made possible by a seasoned knowledge of the proportions of the various elements of the plants and by a better understanding of the requirements for efficient operation. The differences are best illustrated by a comparison of the North Side and the Southwest plants.

At the time of designing the North Side plant, there was considerable doubt as to the amount of preliminary treatment desirable, the optimum aeration period, and the necessary area for final settling. To provide for major changes that experience might dictate, the various parts of the plant were rather widely separated in order that additions could be made in almost any direction. Three separate buildings were provided to house the sewage pumps and air blowers, the sludge return pumps, offices and laboratories, and the service facilities, respectively. Likewise, very elaborate controlling and metering equipment was provided.

In contrast, the Southwest plant is very compact for its size. The aeration and final settling tanks of the present installation are in one block, with all conduits, pipe lines, and service tunnel connecting at one side, while provision for extension is made at the opposite side. Sewage pumps, air blowers, steam generating units, sludge filtering and incineration, offices, laboratories, shops, storerooms and garage are all housed in one building, with no sacrifice in operating efficiency and with considerable economy in first cost. This compact layout has made practical the connecting of all parts of the plant with service tunnels. These contain the air, sludge, water and service piping and electrical ducts and also provide underground walkways for use in inclement weather. Control equipment has been reduced to a practical minimum. Indicating meters are used for equalizing flow to the individual tanks while recording and integrating instruments are provided only for the battery controls or other major units. Another feature of the compact layout is a great flexibility of interconnections in conduits, making it possible to by-pass any part of the plant.

Conclusion

In tracing some of the main developments which have taken place in the design of the Sanitary District's treatment works in their successive stages, in this rather general and informal way, we have attempted to emphasize the important part that continued study, investigation, and experiment, often on a plant-size scale, have played in the improvements and economies which have been made in the later works. Only a very few of the many investigations and experiments which have been carried out in the last 15 years have been mentioned. They have covered a wide range of subjects, not only in the fields of sewage treatment and sludge disposal proper, but in allied lines such as investigations of hydraulic phenomena and corrosion effects of sewage liquids and gases on materials of construction and preservative coatings.

In conclusion, it is pertinent, although perhaps unnecessary, to state that some of the important developments upon which stress has been laid in this paper are applicable only to plants of such magnitude as those of the Sanitary District. In small treatment works, or even in those of moderate size, some of the features which we have found both desirable and economical would be entirely out of place from the standpoints of proper plant flexibility and operating economy. It should also be noted that the designs for all of the Sanitary District plants are always influenced by the fact that weak sewage averaging roughly from 100 to 145 p.p.m. of suspended matter and 75 to 125 p.p.m. of 5-day B.O.D. is dealt with in all cases.

The development of the construction program of major treatment works for the Sanitary District started under the direction of Edward J. Kelly as Chief Engineer, followed by Philip Harrington, as his successor. The present engineering staff consists of Wm. T. Trinkaus, as Acting Chief Engineer, Horace P. Ramey and Walter H. Faget, Assistant Chief Engineers, Langdon Pearse, Sanitary Engineer, Homer I. Steffa and Wm. A. Dundas, Engineers of Mechanical Design, John T. Hawley and Frank W. Hinze, Electrical Engineers, Ralph R. Leffler, Engineer of Structural Design, Frank L. Finlayson, Architect, O. L. Eltinge and P. F. Girard, Engineers of Sewer Design, L. B. Barker, Engineer of Construction, and the writers as Engineer of Design and Engineer of Treatment Plant Design, respectively. Lloyd M. Johnson is Engineer of Maintenance and Operation, and Dr. F. W. Mohlman is Director of Laboratories.

Since December 16, 1933, the construction work of the Sanitary District has been financed by a loan and grant from the Public Works Administration of the Federal Government to the total extent of $58,630,000. The Public Works Administrator is represented by Mr. Joshua D'Esposito, as Resident Projects Engineer for the Sanitary District work. Mr. D'Esposito has been aided by a reviewing board, consisting of Messrs. Daniel W. Mead, Charles W. Kutz, and W. B. Storey.

IMPROVEMENTS IN SEWAGE TREATMENT AT STOCKTON, CALIFORNIA, AS AFFECTED BY CANNERY WASTES

By Clyde C. Kennedy *

Consulting Engineer, Call Bldg., San Francisco, California

An excellent paper was presented a year ago at the meeting of the California Sewage Works Association in San Francisco by William T. Ingram, Sanitary Engineer, San Joaquin Local Health District, on "The Relation of Industrial Wastes to the Sewage Load at Stockton, California." When the conditions of gross pollution existing in the San Joaquin River and adjacent channels, described in Mr. Ingram's paper, were brought to the attention of the public, bonds were voted for improvement of the sewage treatment plants of the City of Stockton.

The studies for the preliminary report, on the basis of which improvements now under construction were designed, were begun January 1, 1936. At that time of the year, the industrial load was at a minimum. In fact, the only industrial waste of any importance being dumped into the river was from the fibreboard plant, which operates throughout the year. A program of continuous sampling of sewage at each of the two existing sewage plants was carried on over a period of a week, and the laboratory work was carried over a period sufficient to give the five-day oxygen demand during the period of sampling. Samples were taken of the fibreboard waste to determine the load imposed on the river.

This work gave a general picture of conditions prevailing in the period of the year when only the all-year sewage load was being discharged. At the same time, samples were taken in the river over a range of tide conditions approximately the same as those covered by the river survey conducted in the summer of 1935 by Messrs. Reinke and Foster of the Bureau of Sanitary Engineering, State Department of Health, and Mr. Ingram, and described in his paper.

Certain physical conditions which determine the capacity of the San Joaquin River (Fig. 1) at Stockton for the disposal of sewage effluent should be noted. The location of Stockton at the head of the tidal estuary makes the problem of sewage disposal similar to the disposal in bay waters. The summer flow in the San Joaquin River past Stockton is so small as to have little value for dilution of the organic wastes discharged by the city. The movement of the water in the San Joaquin River and adjacent channels is for the most part due to the movement of a tidal prism under the influence of the tidal range, with a movement downstream on the outgoing tide and back upstream on the incoming tide. Under these conditions the diffusion of fresh water from San Francisco Bay or the Sacramento River takes place very

* Presented before the Ninth Annual Convention of the California Sewage Works Association, Santa Monica, Sept. 11, 1936.

slowly and has little value in providing a fresh supply of water for dilution purposes.

Considerable study was given to this phase of the problem to determine as nearly as possible the capacity of the stream to receive and dispose of organic wastes. Undoubtedly during the critical summer season the oxidation and disposal of the organic wastes is effected principally by the oxygen absorbed by the tidal prism moving back and forth and the oxygen liberated in the water by the algae and other aquatic life growing therein.

In order to determine within reasonable limits the surface area of the tidal prism moving past Stockton, an analysis was made of the probable velocities and consequent distance of travel through the tidal cycle. Under the conditions assumed, the distance the water will travel on each tide was estimated between 5 and 6 miles during the critical period of late summer. The water surface available for oxygen absorption

FIG. 1.—San Joaquin River, near outfall of the North Plant.

in the river, channels and adjacent sloughs between 5 miles downstream from the point of discharge of the North Plant and 3 miles upstream from the South Plant is approximately 750 acres.

The studies conducted by the Bureau of Sanitary Engineering, State Department of Health, in 1930 and incorporated in Bulletin 28, Division of Water Resources, Department of Public Works, State of California as Appendix E, presented this phase of the problem very clearly. Fig. 2, taken from the above report, shows the curve of oxygen absorption under various conditions of oxygen depletion and wind action.

No definite data were available on the amount of oxygen liberated in the San Joaquin River and connecting channels by plant growth. Somewhat meager data were available on the amount liberated in eastern waters under favorable conditions. These showed that the liberation may be in excess of 17 lb. of oxygen per acre of water surface per day. The conditions promoting a high rate of liberation are bright

sunlight, reasonably clear water and temperature of the water high enough to stimulate plant growth. When the water is cold and turbid and the sky is overcast, the rate of liberation is greatly decreased. In winter the microscopic plant life dies down and in its decomposition exerts a demand on the oxygen in the stream instead of liberating oxygen. In summer there is a prolific growth of algae along the banks and in the quiet waters of the San Joaquin River, channels and sloughs.

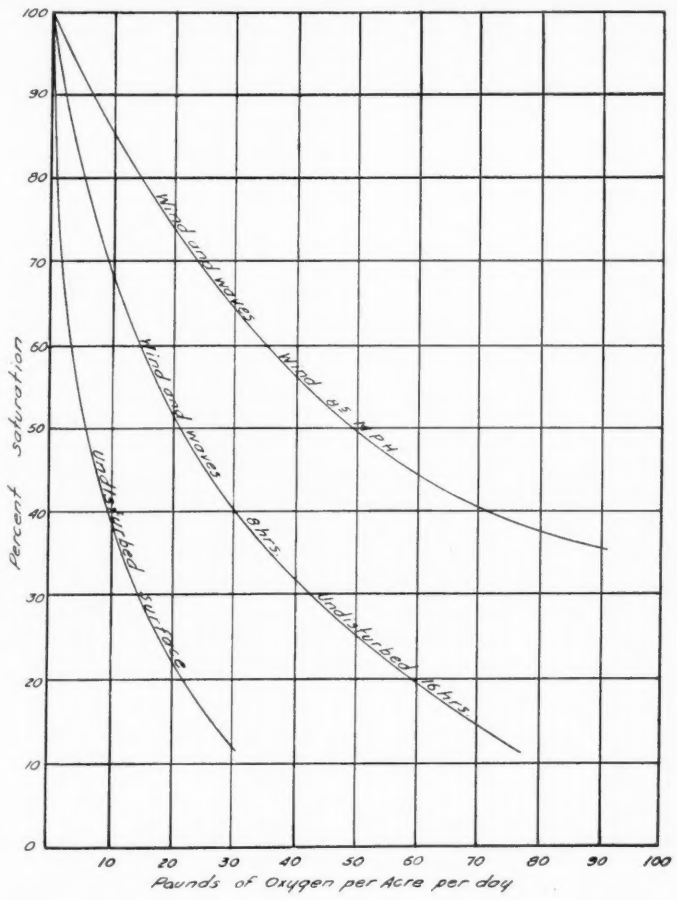


FIG. 2.—Oxygen absorption from atmosphere.

In that period it appeared reasonable to assume a rate of oxygen liberation approximately as high as has been observed on the eastern coast.

Summarizing the above data, it was concluded that the receiving waters at Stockton have the capacity to dispose of an organic load and its consequent biochemical oxygen demand in an amount equal to the available regenerative oxygen, determined by the allowable oxygen depletion in the receiving waters. The quantity of such oxygen at any

time is the sum of the amount available by depletion of the normal dissolved oxygen in the downstream flow, the amount absorbed from the atmosphere under the allowed degree of depletion and the amount liberated by plankton growth.

To determine the amount of organic load that might be safely imposed on the river and connecting channels during the critical period, without exceeding the assumed safe limits of an average dissolved oxygen depletion not exceeding 40 per cent, or 3 p.p.m. for the summer temperature then prevailing, the following tabulation was made up, showing available regenerative oxygen in pounds per day:

Surface absorption, 20 lb. per acre over 750 acres	15,000 lbs.
Liberated by plant growth, 15 lb. per acre over 750 acres	10,750 "
River flow, 200 sec. ft., 3 p.p.m.	3,250 "
Total	29,000 lbs.

For the purposes of design, we assumed that the daily oxygen demand load imposed by the discharge of organic wastes should not exceed the amount determined above.

The collecting sewers of Stockton are in two systems; one serving the area north and the other the territory south of the channel. The sewer leading to the North Plant has a safe estimated capacity of 9 m.g.d., while the sewer leading to the south plant has a safe estimated capacity of 8 m.g.d.

At the North Plant, records of flow have been kept by charting the rate of discharge of the entering trunk line sewer hourly. These records show an hourly maximum dry weather flow of 5.7 m.g.d. Because of storm water reaching the plant, the flow has increased to a rate of 9.5 m.g.d. on three occasions in the past five years.

At the South Plant, the measurement of sewage flow has been computed from the pumping record, and therefore there is reliable information only for the total daily flow. The maximum and minimum rate were estimated by the length and frequency of the pumping periods. The maximum rate was 4.0 m.g.d. for a one-hour period.

In addition to the discharge from the sewage works mentioned above, the wastes from the Fibreboard Products, Inc., discharge separately into the McDougald Canal. This canal, which, during the dry period, carries no water except that discharged by the fibreboard plant, is tributary to Mormon Channel (Fig. 3). The flow is a combination of industrial waste and the sanitary sewage from the plant. The daily flow, estimated at 3.0 million gallons, is discharged at a nearly uniform rate.

The laboratory analyses made on the samples collected in January, 1936, furnished the basis for estimating the organic load at that time These computations indicated that at the North Plant the organic content (volatile solids) varied from slightly under 6000 lb. to 12,845 lb per day. At the South Plant the organic load varied between 4,600 lb and 6,700 lb. per day.

The 5-day B.O.D. of the sewage at the North Plant was considerably lower per pound of organic matter than that of the South Plant. The former was estimated to be .51 lb. B.O.D. per lb. of organic solids, and the latter .61 lb. per lb. of organic solids. The waste from the fibreboard plant differed considerably from the plant sewages in B.O.D. The organic content was 16,140 lb., with an estimated 5-day B.O.D. equivalent to .382 lb. per lb. of organic solids.

Based on the above studies, it appeared that under the conditions prevailing in January, there was an average daily discharge of 30,840 lb. of organic matter and 14,300 lb. of B.O.D. to the North and South Plants and into McDougald Canal.

A great portion of the industrial load is seasonal, coming from the fruit canning plants which operate more or less continuously from the first of March to early in November. None of these plants were in operation during the period when the field studies and analyses of sewage

FIG. 3.—Mormon Channel, Stockton, California. Note floating sludge.

were made. Their influence was observed in the river studies made by Mr. Ingram and the Bureau of Sanitary Engineering in September, 1935, and the condition of the river at that time with respect to dissolved oxygen was shown.

In an effort to arrive at a reasonable estimate of the total organic load and the probable oxygen demand imposed on the receiving waters in the most critical period, a careful canvass was made of the plants which operate seasonally and which were not in operation during the week of Jan. 6 to 13, 1936. In this survey the daily capacity of the plant of the particular food product being handled, the probable amount of waste, the probable organic content and the probable total contribution to the sewage flow in gallons was sought.

The canning waste includes all waste material from the canning of fruits and vegetables, except pits from apricots and peaches. It was assumed that the wastes now being hauled away from the plants and dumped would be ground and disposed of through the sewerage sys-

tem. The estimates of organic matter in the wastes were computed from the laboratory reports of two large canning companies. The oxygen demand of the organic matter was considered similar to that of domestic sewage. The tonnages of fruit and vegetables were secured from data collected by the State Department of Public Health and the San Joaquin Local Health District, as reported by the packing companies.

The daily capacity of the combined industries in tons daily of fruit and vegetables handled by canning companies contributing to the two plants is tabulated below:

	North Plant	South Plant
Spinach	90	190
Asparagus	110	—
Peaches	500	170
Tomatoes	300	270

From the analyses of the waste material the following tabulation was prepared:

	Per Cent Waste	Per Cent Org. Mat. in Waste	Lb. Org. Mat. per Ton	Lb. Oxygen Required per Ton
Spinach	25	13	65	33
Asparagus	47	6	56	28
Peaches	12	20	48	24
Tomatoes	25	19	96	48

The following canning periods were used:

Spinach	March 1 to April 1
Asparagus	April 1 to July 1
Peaches	July 1 to Sept. 1
Tomatoes	August 15 to Nov. 1

Combining the data given above, Table I was made up, showing the expected load in sewage flow, in organic matter and in 5-day B.O.D. for each period of the year, together with the equivalent domestic population for that period. The 5-day B.O.D. was based on an assumed oxygen demand for the seasonal industrial organic waste of .5 lb. B.O.D. per lb. of organic matter. In this table it is shown that the total daily organic load from domestic and industrial sources probably would be, during the most critical summer period, 105,000 lb., with a probable 5-day B.O.D. of 51,500 lb.

It was assumed that the entire waste product of the canneries, except peach and apricot pits, was discharged to the plants. As a solution of the canning waste problem it is more economical to combine all wastes that require similar treatment, prior to reduction and disposal, in order to avoid the creation or continuance of local nuisance. From a practical point of view any other assumption will give a false sense of

adequacy to sewage treatment facilities. The cost of hauling solid wastes away from the plants and the difficulty of providing areas where such wastes may be dumped without violent objection from adjacent land owners combine to influence plant operators to convert as large a part of the wastes as possible into a liquid state which will flow without detection into the sewers. This has already been done in some of the plants in Stockton.

Against an assumed safe load, equivalent to a B.O.D. of 29,000 lb. daily, our studies indicated that there would, during the critical period, be produced and delivered to the treatment plants, an organic load with a B.O.D. of not less than 51,500 lb. Because of conditions that have been discussed, the sewage discharged into the tidal prism during the late summer months does not get out of this prism within a 5-day period and, in consequence, the B.O.D. for a 5-day period probably does not indicate the total demand which may be exerted for the oxidation of the organic matter. Based on the results of numerous studies, it is safe to conclude that the 5-day oxygen demand is not more than 70 per cent of the amount of oxygen required to stabilize the organic matter. This ratio, applied to the estimated 5-day demand, would give a total oxygen demand in excess of 70,000 lb. daily.

It seemed reasonable to assume a substantial increase in the growth and industrial development of Stockton during the next ten years. For these reasons, we considered it advisable to provide an increase in the daily organic load of 20 per cent. Under this assumption the expected organic load would be equivalent to 64,300 lb. of 5-day B.O.D. This represented an excess of 35,300 lb. over the assumed safe load. Expressed in other terms, it will be necessary to effect a decrease in the expected organic load of not less than 55 per cent in order to bring it within the amount that may safely be discharged into the river.

The North Plant was constructed in 1919. It consists of a coarse bar rack with 4 in. openings, and a Riensch-Wurl fine screen and pumping plant, housed in a permanent concrete structure. The Riensch-Wurl screen is 12 ft. in diameter with $\frac{3}{64}$ by 2 in. slots. The screenings removed are discharged into buckets, which, when filled, are hoisted by means of a chain block to an overhead mono-rail track, on which they are carried a distance of 100 to 200 feet from the plant and dumped.

The pumping plant consists of three units, one of 1500 g.p.m. capacity, one of 3000 g.p.m. capacity, and one of 4500 g.p.m. capacity, all connected to a header. Any combination of these units can be operated to handle the flow.

The South Plant consists of a coarse bar rack with 4 in. openings, and a pumping plant, housed in a permanent concrete building, and two Imhoff tanks with an aggregate settling chamber capacity of 5500 cu. ft. and a sludge digestion capacity of 40,000 cu. ft. The pumping plant consists of three units, which, under the heads at which they now operate, have capacities respectively of 1650 g.p.m., 3260 g.p.m. and 5000 g.p.m. These pumps discharge into a common header and may

be operated separately or in any combination. The water level in the sump is at elevation approximately 70 ft. and the elevation of the water level in the Imhoff tank is 98.5 ft. above city datum.

The discharge line from the North Plant is a 27 in. precast concrete pipe, which discharges into the San Joaquin River at a point approximately one mile west of the treatment plant. The ordinary static head on this line is from 16 to 24 ft. The static head with a recorded high water level of 97.8 will vary from 26.8 to 34.8 ft. The friction loss in the line for periods of maximum discharge is probably about 6.7 ft.

The effluent line from the South Plant leads directly from the Imhoff tanks in a southwesterly direction to the river, a distance of approximately 700 feet. It is a 30 in. diameter concrete pipe with an estimated capacity of 8 m.g.d. The effluent lines at each of the plants at present discharge at or near the shore line of the river channel, with full size of pipe opening below the water surface.

It was not considered of value to investigate the performance of the existing plants. It was obvious that they were inadequate to meet the

TABLE I.—*Assumed Average Daily Sewage Flow, Organic Load and 5-Day Biochemical Oxygen Demand*

North Plant

	Jan. and Feb.			March			Apr., May, June		
	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen
Domestic Sewage, Laundries, Creameries, Etc.	2.6	9,000	4,600	2.6	9,000	4,600	2.6	9,000	4,600
Spinach	—	—	—	.1	6,000	3,000	—	—	—
Asparagus	—	—	—	—	—	—	.7	6,200	3,100
Peaches	—	—	—	—	—	—	—	—	—
Tomatoes	—	—	—	—	—	—	—	—	—
Total	2.6	9,000	4,600	2.7	15,000	7,600	3.3	15,200	7,700
Population Equivalent		29,000			48,000			48,500	

	July			Aug. 1 to Aug. 15			Aug. 15 to Sept. 15		
	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen
Domestic Sewage, Laundries, Creameries, Etc.	2.6	9,000	4,600	2.6	9,000	4,600	2.6	9,000	4,600
Spinach	—	—	—	—	—	—	—	—	—
Asparagus	—	—	—	—	—	—	—	—	—
Peaches	.2	11,400	5,700	.3	11,400	5,700	.3	11,400	5,700
Tomatoes	—	—	—	—	—	—	1.2	28,800	14,400
Total	2.8	20,400	10,300	2.9	20,400	10,300	4.1	49,200	24,700
Population Equivalent		65,000			65,000			155,000	

	Sept. 15 to Oct. 31			November			December		
	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen
Domestic Sewage, Laundries, Creameries, Etc.	2.6	9,000	4,600	2.6	9,000	4,600	2.6	9,000	4,600
Spinach	—	—	—	—	—	—	—	—	—
Asparagus	—	—	—	—	—	—	—	—	—
Peaches	—	—	—	—	—	—	—	—	—
Tomatoes	.4	28,800	14,400	—	—	—	—	—	—
Total	3.0	37,800	19,000	2.6	9,000	4,600	2.6	9,000	4,600
Population Equivalent		120,000			29,000			29,000	

TABLE I.—*Continued*

South Plant

	Jan. and Feb.			March			Apr., May, June		
	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen
Domestic Sewage, Laundries, Creameries, Etc.	1.5	5,700	3,500	1.5	5,700	3,500	1.5	5,700	3,500
Spinach	—	—	—	.8	12,800	6,400	—	—	—
Asparagus	—	—	—	—	—	—	.7	—	—
Peaches	—	—	—	—	—	—	—	—	—
Tomatoes	—	—	—	—	—	—	—	—	—
Fibreboard	3.0	16,000	6,200	3.0	16,000	6,200	3.0	16,000	6,200
Total	4.5	21,700	9,700	5.3	34,500	16,100	5.2	21,700	9,700
Population Equivalent		61,000			100,000			61,000	

	July			Aug. 1 to Aug. 15			Aug. 15 to Sept. 15		
	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen
Domestic Sewage, Laundries, Creameries, Etc.	1.5	5,700	3,500	1.5	5,700	3,500	1.5	5,700	3,500
Spinach	—	—	—	—	—	—	—	—	—
Asparagus	—	—	—	—	—	—	—	—	—
Peaches	.6	8,200	4,100	.5	8,200	4,100	.4	8,200	4,100
Tomatoes	—	—	—	.5	—	—	.7	26,000	13,000
Fibreboard	3.0	16,000	6,200	3.0	16,000	6,200	3.0	16,000	6,200
Total	5.1	29,900	13,800	5.5	29,800	13,800	5.6	55,900	26,800
Population Equivalent		87,000			87,000			169,000	

	Sept. 15 to Oct. 31			November			December		
	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen	Flow M. Gal.	Lb. Org. Matter	Lbs. Oxygen
Domestic Sewage, Laundries, Creameries, Etc.	1.5	5,700	3,500	1.5	5,700	3,500	1.5	5,700	3,500
Spinach	—	—	—	—	—	—	—	—	—
Asparagus	—	—	—	—	—	—	—	—	—
Peaches	—	—	—	—	—	—	—	—	—
Tomatoes	1.3	26,000	13,000	—	—	—	—	—	—
Fibreboard	3.0	16,000	6,200	3.0	16,000	6,200	3.0	16,000	6,200
Total	5.8	47,700	22,700	4.5	21,700	9,700	4.5	21,700	9,700
Population Equivalent		143,000			61,000			61,000	

Note: The above flows make no allowance for storm water peak discharges.

demands then made upon them. It was our purpose to work out a practicable solution of the problem of treatment of the domestic sewage and industrial wastes which existed, with reasonable provision for growth; and to utilize, to the maximum degree possible, the existing treatment plant units. This purpose was determined, to some degree, by the fact that the amount of money which would be available had already been set up in the proceedings under way to provide the necessary funds.

The plan for the North Plant provides for the construction of a sand removal unit ahead of the Riensch-Wurl screen of sufficient capacity to remove all plus-65 mesh sand and grit. The quantity of grit will probably vary from a dry weather low of one or two cu. yd. per day to possibly 15 to 20 cu. yd. per day in times of high storm water flow.

The existing Riensch-Wurl screen effects a very positive removal of the coarser suspended solids. With the character of waste coming to

the plant in the summer season when the canneries are operating, this removal is of very great value. It has been observed that when heavy canning waste loads are discharged into sedimentation tanks, a considerable portion of the skins and similar fibrous matter will neither rise to the top, where it may be skimmed off, nor sink to the bottom. It remains suspended in the intermediate zone of tank liquid and passes out with the effluent. A considerable portion of the suspended organic waste load thus escapes, resulting in a lower efficiency of the plant. As an aid in removing this portion of the wastes, the screen will be of great value, and will obviate the requirement of a fine bar rack.

The discharge line from the pumps will lead to a sedimentation tank set at such an elevation that the effluent will discharge by gravity through the present outfall line. With the assumed high water level in the river of 97.8 ft., a weir elevation of 103.5 ft. has been selected. A free board of 18 in. above this level provides an ample factor of safety against all probable flood conditions.

A tank 90 ft. in diameter with a sidewall water depth of 15 ft., meets the physical conditions at the plant site. This tank provides for a detention period of 2½ hr. and 1000 gal. per sq. ft. per day overflow rate for a flow approximately 20 per cent in excess of the estimated maximum rate for a 3-hour period, under the most critical summer flow conditions.

The disposal of the sludge from the sedimentation tank and the fine screenings at this plant was the most difficult part of the entire disposal problem. The location of the plant adjacent to the new city park and country club, and in comparative proximity to residential development, which is rapidly assuming a higher type, made the disposal near the present plant particularly difficult. The usual and most economical method of disposal, by digestion in tanks and drying the digested sludge on beds, appeared entirely unsuited to these conditions. The required area of the sludge drying beds for the estimated summer load would have been not less than 2.4 acres. This area at this location would have required the purchase of probably 10 acres of land. This amount was necessary to provide the minimum width of buffer strip recommended by the Bureau of Sanitary Engineering, State Department of Health. The estimated cost of the digestion tanks, including provision of gas collection and burning, together with the cost of the sludge drying beds and additional land required, was in excess of $100,000. This amount of money, added to the cost of the essential units already described, exceeded the total funds available and precluded the possibility of making the vitally necessary improvements at the South Plant. It was, moreover, questionable whether this method of disposal might not, in the near future, meet with local objection.

As the most satisfactory and most economical solution of this problem, it was provided that the sludge from the sedimentation tank be collected in a sump, to which the screenings from the fine screen will be discharged after grinding in a hammer mill. The combined solids will be pumped from this sump through a pressure line approximately

10,000 feet long to the existing Imhoff tanks at the South Plant. There the sludge will be mixed with the sludge from the South Plant and the combined mixture disposed of as described later. By the adoption of this plan, the only process of sewage treatment which was likely to be subject to local objection at this plant—*i.e.* sludge handling and disposal—was eliminated. The sludge can be much more readily disposed of at the South Plant, where the isolation is good and the area owned by the city is ample and where more land may be acquired at a much lower cost than at the North Plant.

The incoming pipe line at the South Plant has an estimated capacity when flowing full of 8 m.g.d. This is sufficient for the present flow plus an allowance of 20 per cent for increased flow. The condition of Mormon Channel due to the Fibreboard Products plant waste has been discussed. Because of the burden imposed on all the waters in the San Joaquin River and channels by this waste, it appeared imperative to treat the waste. The discharge of the sanitary sewage with the plant waste in an otherwise dry channel, along the course of which are many residences, threatened a distinct and important menace to health. For these reasons, it is planned that the discharge from the plant be connected directly to a new trunk line sewer leading to the South Plant. The discharge line now in use is ample in capacity to carry the total expected flow. In this plant, the pumping capacity is ample to meet any anticipated demand.

The plan provides for constructing a sand removal unit at the South Plant similar to that recommended for the North Plant. Since the flows at both plants with high storm water discharge will be nearly the same, the size for each, as recommended, is the same; namely, a capacity of approximately 8½ m.g.d.

For the same reasons that the continued use of the Riensch-Wurl screen at the North Plant was considered necessary, the construction of a fine screen unit has been provided for the South Plant instead of a bar rack. The leveling off of the peak load, which would otherwise be thrown on the sedimentation tank, and the improved effluent possible through its use, will, in my judgment, warrant its extra cost. The screen unit is provided with a bucket elevator to elevate the screenings which, as at the North Plant, will be ground in a hammer mill and discharged with the sludge from the sedimentation tank.

The discharge line from the pumps will also, in this plant, be carried to a sedimentation tank with the weir elevation set to provide for gravity discharge through the existing effluent line at all stages of the river. A weir elevation of 100.0 ft. with an 18 in. freeboard safely meets this requirement. With the assumed weir elevation, a tank with side wall water depth of 15 ft. and 100 ft. in diameter will provide an overflow rate of 1000 gal. per sq. ft. per day and 2½ hours detention period for maximum flow rate, 20 per cent greater than that estimated for a 3-hour period for the critical summer season.

The sludge from the sedimentation tank will be drawn to a sump into which the finely ground screenings will also be discharged. This

sludge will be pumped to the existing Imhoff tanks where it will be mixed with the sludge pumped from the North Plant. The sludge pumping unit consists of two pumps, each of 250 to 300 g.p.m. capacity, either of which has sufficient capacity to deliver the estimated quantity of sludge to the Imhoff tanks in eight hours.

It is proposed to utilize the entire capacity of the existing Imhoff tanks for holding the sludge. To do this, the existing flowing-through chambers will be removed. The tanks have a capacity of 60,000 cu. ft., which will provide a holding period of from 2 to 7 days. This holding period will, it is expected, result in materially reducing the water content of the sludge. It is proposed to draw the thickened and partially digested sludge into lagoons constructed in the area between the Santa Fe Railroad and the San Joaquin River, which now belongs to the city and is used in part for sludge beds. In these lagoons it will be allowed to digest and dry. After the moisture content is sufficiently reduced, the digested sludge will be removed from the lagoons by steam shovel or dragline, and hauled away for use as a soil conditioner and fertilizer or for filling.

The decision to use this method of sludge disposal does not preclude the adoption of some other method at a later period when funds are available, if lagooning should prove inadequate or unsatisfactory. By that time, there will have been opportunity to study the characteristics of the sludge and its amenability to tank digestion or other type of disposal which might prove more desirable.

The bids for the construction work as planned exceeded by some $6000 the amount of money available. After considerable discussion it was decided to eliminate the grit removal units from the original contract and the work is now proceeding under this revision of plan. All of the excavation and retaining walls, providing space for the installation of the grit removal units, will be included in the present contract. It is hoped to provide additional funds to complete the plant as planned at an early date; if possible before the other units are ready to go into operation. The contract cost for the work as awarded is approximately $137,000.

The contractor is the M. J. B. Construction Company of Stockton. The construction work is being carried out under the supervision of Lyle Payton, City Engineer. The plans and specifications were prepared under my direction, in collaboration with the office of the City Engineer.

Discussion

Mr. Kennedy: I have suggested to your president that we should hear from someone other than myself with regard to the Stockton plant and he has invited Mr. Lyle Payton, city engineer of the city of Stockton, to discuss some of the problems of construction and operation of this plant for you.

Mr. Payton: I think the most striking thing to me today in listening to Mr. Kennedy's report on the solution of our sewage problem—is the fact that— he "answered the question" for us.

As he has stated, Mr. Ingram gave a very condemning paper last year at San Francisco. At the conclusion of his paper the chairman called for discussion of the subject and a gentleman behind me asked this question: "What is the city of Stockton going to do about it? . . . which question came from Mr. Kennedy himself. Little did he or I then know that the solution of the problem would be placed in his hands. Shortly thereafter the San Joaquin local health district and our city fathers decided there must be something done to alleviate the condition of the San Joaquin River. The funds provided, as we later found out, were rather meager, and we are very fortunate to have had Mr. Kennedy's design in awarding a contract. The funds provided included an excess of $20,000 over the bond issue. This excess was taken from available funds on bond.

Work on the North Plant started about the middle of July, 1936, and progress was rather slow. There were water difficulties in connection with the footings of the structures but later on we encountered conditions much more favorable than we had anticipated. The area in which the plants are located is adjacent to the San Joaquin River at an elevation close to sea level, and ground water during the winter is very close to the surface. Fortunately, by the time the contracts were let the water had pretty well receded and we were able to secure fairly good foundation conditions. Work on the North Plant is now well under way: the walls and foundations are complete for housing of the screens, pumps and sludge pit. The foundation for the clarifier has been completed and that is the one which gave us the most concern. Investigations at the time of its design indicated that the soils were of insufficient stability to carry the relatively light load of the tank and we therefore had to make an excavation of from 3 to 5 feet of a light peat soil, substituting for it a fine sediment from the Calaveras River which was available a short distance away. We thus succeeded in preparing and perfecting an excellent foundation for the tank.

With the work under way we are very well pleased with the design prepared by Mr. Kennedy—and we have every reason to believe that the pollution of the San Joaquin River will be eliminated to a very satisfactory degree.

Mr. Ingram: In the first place, I would like to say here and now that we are exceedingly fortunate in Stockton in securing Mr. Kennedy's services. As you noted in his report, he very carefully went into detail to show us the vagaries of industries. I understand, however, that plans are now well under way for the enlargement of canneries in Stockton and the industrial wastes flow will probably exceed his 20 per cent estimate in considerably less than ten years—and undoubtedly there will have to be an addition to the Stockton plant in the very near future. With all due respects to Mr. Kennedy and his splendid accomplishment for the city of Stockton, we do have that problem still confronting us and sooner or later Stockton will again be behind the times. We all know pretty well how to estimate sewage flows from domestic sources—but when it comes to industrial wastes, it just can't be done.

Mr. Gray: I was impressed with Mr. Kennedy's report and with the manner in which he has approached the problem of industrial wastes. . . . I have heard, at various times, ideas put forth with regard to eliminating certain kinds of wastes that are being sent down our sewers by forbidding them to be turned into the sewers, and I have always felt that is a mistake. . . . I think we will have to take whatever sewage and industrial wastes are given to us and meet the conditions that arise in their treatment and disposal.

Mr. Kennedy: We had to keep always in mind the amount of money which was allowed for the project. We couldn't come right out and say we would have to demand a 40 per cent increase, the people wouldn't let us do it at all, and so we had to edge them along until we got them this far. What we have laid out represents approximately the margin you may expect to get economically with plain sedimentation. Attention has been called to the fact that there are now available various aids to treatment such as: mechanical flocculation, chemical treatment, magnetite filters, . . . etc. . . . We have had to cut the suit to fit the cloth.

Mr. Parkes: It seems to me that where an industry is burdening a treatment plant, and runs up not only the cost of construction but of operation as well, the industrial plant should be required at least to relieve that load. By that I don't recommend turning out a potable effluent. Where a cannery is discharging an organic load two or three times that of the rest of the city—that industrial plant should be required to effect at least a partial treatment of the waste before sending it on to the treatment plant. There are certain cases where industries have been required to treat their wastes and have derived a profit thereby. I would say that if possible they should be required to reduce the load to some extent.

Mr. Gray: Improvements and recovery will not only lighten the load for the treatment plant but may bring profit to the industry. However, I still say I do think we will have to face the situation as it is and make the most of it.

Mr. Stevenson: I suggest that we hear the views of the operator of the Stockton plant?

Mr. West: The city went to work and voted those bonds, with the consequence that they ran into objections. After the plans had been submitted and they found there wasn't enough money, they commenced eliminating, cutting down, until I wondered if we would get *anything* before it was over. We do have one satisfaction—they have started the excavation! I am only hoping that a miracle will happen—that somebody will uncover an old pirate's treasure, or something—and we will have enough money to complete the plant.

COAGULATION CONTRASTED WITH CHEMICAL PRECIPITATION IN SLUDGE FILTRATION

By A. L. Genter

Chemical Engineer, Baltimore, Maryland

This article is intended primarily as a discussion of the relative merits, during suction filtration, of using precipitants such as iron salts and lime or sludge elutriation followed by the addition of a simple coagulant. As indicated by the title, a distinction is made between precipitation and coagulation. As the economics of filtration of sewage sludges is involved in understanding this distinction, some explanation is desirable.

In a precise chemical sense the term *precipitation* means the process of making certain soluble substances (salts and ions) insoluble by the addition of some soluble reacting substance. The insoluble precipitate thus produced can appear and persist as dispersed cloudiness or it can gather in larger particles that rapidly settle, or it may even appear as gelatinous clusters. In the realm of colloid and capillary chemistry, *coagulation* or *flocculation* applies more to the coalescence or congealing of finely dispersed particles or insoluble amorphous complexes into larger and coarser agglomerates by some simple procedure, namely stirring or the addition of some highly ionized substance. Precipitation should therefore apply only to reactions of matter in solution, while coagulation or flocculation should apply to matter that is not in solution but rather in some colloidal state. The sanitary chemist correctly defines the coalescence of dispersed colloidal matter in water or sewage into larger agglomerates by stirring as flocculation. However, if precipitate-forming chemicals are used in this process, actual chemical precipitation will be the initial result.

Therefore considerable confusion can be avoided by understanding this distinction. It is true that a great many chemical precipitates can be colloidally dispersed or have gelatinous colloidal properties. It is likewise true that these precipitates can be materially coarsened by flocculation or coagulation.

Some Facts About Chemical Precipitation.—In separating chemical precipitates from water on vacuum filters the granular, drainable structure of the precipitate is of prime importance. This should be under control. However, in chemical precipitation all kinds of precipitates can be formed by the interaction of various chemical solutions. The mere fact that these precipitates are formed in predictable amounts gives no indication of their behavior when subjected to partial dewatering by simple filtration. As is very well known, precipitates of the hydroxides of calcium, iron and aluminum can exhibit distinct colloidal surface properties, namely, they can be gelatinous, filled with minute capillaries and therefore highly hydrated and quite capable of definitely blinding any commercial filter medium. Mixtures of these

gelatinous hydroxides with more granular carbonate or phosphate precipitates may entirely change the dewatering properties of the former. A certain excess of precipitates of ferric, calcium or aluminum hydroxide in any sludge cake may easily cause smears and cloth blinding, whereas a certain amount of calcium carbonate in the cake may eliminate such action.

Consequently chemical precipitates can cause distinct filtration difficulties and unless the ingredients involved in producing the precipitates are definitely known by analysis and under control, the amounts used are of no value in predicting and governing the dewatering properties of the precipitates.

Some Facts About Coagulation.—In dealing with the colloidal surface properties of amorphous solids in sewage and sewage sludges it is known that the solids in the coagulating reaction are *not in solution,* but nothing is known about the dispersion of the solids involved and the extent of the adsorbing surfaces. Although coagulation can be caused by adding small amounts of certain electrolytes, or even by stirring, chemical equations cannot be used to express the reactions in predictable weight proportions. This is an important distinguishing characteristic between chemical precipitation and coagulation by the use of electrolytes, which are herein called *coagulants.*

The other points of practical importance to remember are: (1) Ion adsorption by colloids is preferential and specific. (2) Colloidal dispersions are not permanent like true solutions, *i.e.* they tend to coalesce slowly to larger aggregates. Such coalescence, or flocculation, can frequently be hastened by stirring. However, the floccules so produced are too amorphous to be satisfactorily dewatered on a vacuum filter. (3) The addition of a coagulant that will neutralize the charges on the dispersed surfaces or separate the absorbed ions, is necessary to produce the maximum shrinkage of the highly amorphous solid surfaces and to coalesce them into more compact coarse aggregates. (4) Most colloids encountered in raw and digested sludges are negatively charged as a result of adsorption and can be coagulated by small quantities of certain positive coagulants when surrounded by pure water. (5) The higher the valence of the positive coagulating ion the greater is its coagulating power, *i.e.* the smaller is the amount needed to produce the same coagulation. (6) The velocity of this coarsening is usually more rapid than is the case with chemical precipitation. In fact with the latter coarsening may be practically absent.

Chemical Precipitation and Sludge Filtration.—Solutions of ferric chloride, ferric sulphate, chlorinated copperas, aluminum chloride and aluminum sulphate contain trivalent electrolytes and are therefore excellent sludge coagulants. They also form precipitates with lime, bicarbonates, sulphides, fatty acids and other soluble compounds ordinarily found in the moisture surrounding sludge solids. Compared with these trivalent electrolytes, lime is relatively cheap.

Any of these compounds can be added separately to sludges to form precipitates with the soluble decomposition products in the sludge mois-

ture and to coagulate the sludge solids. However, when used individually, those precipitates and flocs formed by the addition of aluminum chloride, ferric chloride, chlorinated copperas and ferric sulphate are the only ones that can be successfully handled on an ordinary vacuum filter.

In the effort to use smaller quantities of ferric salts and to make direct use of the bicarbonates in sludge moistures, the addition of milk of lime has been employed in rendering raw and digested sludges dewaterable on vacuum filters. The use of lime and ferric salts together on such sludges is made possible by the chemical compounds in solution in the sludge moisture.

The bacterial decomposition of raw sludge through detention is responsible for the liberation of a number of soluble compounds that accumulate in the relatively large volume of water surrounding the sludge solids. For example, sewage solids are rich in matter of protein origin. A large number of amino acids and amino compounds result from the initial decomposition of proteins. The amino acids are primarily broken down by microorganisms in two ways, namely, the amine (NH_2) groups are split off and ammonia and fatty acids result (deamination), or the carboxyl (COOH) groups are split off and numerous amines and carbon dioxide result (decarboxylation). As both types of reactions occur in normal putrefaction, the liberated ammonia and carbon dioxide can unite to form ammonium bicarbonate in the sludge water. Ammonia may also combine with the resulting fatty acids and numerous other organic acids. A great number of other biochemical reactions undoubtedly occur and result in the evolution of objectionable gases and soluble complexes, which are mostly acid in nature. These types of putrefaction are common to raw sludge.

In sludge digestion anaerobes are cultivated and the sludge decomposition is held under control. Although deamination and decarboxylation proceed, the resulting fatty acids and other compounds are all broken down to much simpler and odorless compounds, such as methane, nitrogen, carbon dioxide and hydrogen. The ammonia remains trapped in the sludge water mainly as ammonium bicarbonate. The water becomes alkaline.

In adding ferric salts and lime to any sludge, both chemical precipitation and coagulation of sludge solids takes place. Ferric salts and lime will react with ammonium bicarbonate and various fatty acids to form insoluble precipitates of hydrated ferric oxide, ferric soaps, lime carbonate and lime soaps, and the ferric salts and lime will react to form hydrated ferric oxide. Practically all of these precipitates except lime carbonate are very gelatinous and difficult to filter. Although hydrated ferric oxide is highly gelatinous and colloidal in nature its surface charge is opposite to the charge of most sludge solids.

The amount of the precipitates formed will be determined by the amount of the precipitating decomposition products in solution in the sludge water and the amount of water present in the sludge. The concentration of these precipitating compounds in the sludge water de-

pends on the degree to which decomposition has proceeded. Dewatering raw sludge by chemical precipitation becomes progressively more difficult with increases in the degree of putrefaction.[1] The resulting precipitates of lime and iron become so gelatinous that nothing but unfiltrable smears result. However, the opposite holds true with digested sludge. Here digestion has to proceed far enough to break down the amino and fatty acids into ammonium bicarbonate and other simpler compounds that do not result in too much gelatinous precipitate. The longer the sludge is detained in digestion the less danger there is of producing filter smears when lime and ferric salts are used for precipitation. However, in digesting activated sludge the resulting concentration of ammoniacal compounds in the sludge moisture can become great enough to render the sludge practically unfiltrable when using economic quantities of ferric chloride alone or together with lime.

In addition to a number of complex chemical precipitating reactions that result when using lime and iron precipitants, some flocculation of sludge colloids evidently occurs. Under conditions involving the precipitation of the positively charged ferric hydroxide there is probably some coagulation of this gelatinous precipitate and the sludge colloids because of the negative charge of the latter. Calcium hydroxide may have some slight effect on the sludge solids. However, an excess of this reagent can cause dispersion and result in cloth blinding.

The resulting porous nature of the precipitate is largely due to the presence of bicarbonates and carbonates in the sludge moisture which form agglomerates of calcium carbonate. If it be desired to confirm this statement, the soluble bicarbonates can be removed, either by elutriation or by other methods, followed by the addition of ferric chloride and lime. This treatment will result in the formation of hydroxides of lime and iron without the formation of precipitated lime carbonate. A relatively unfiltrable mass will result, although chemical precipitation and coagulation have definitely taken place. The excessive amount of gelatinous precipitates formed will obliterate the coarsening effect produced by coagulating the sludge solids and definite filtration difficulties result.

In using lime and ferric salts on sludges, chemicals are added to other chemical compounds naturally present in the sludge water. The true solution reactions are first completed and are used to form precipitates which aid in rendering the entire sludge dewaterable by filtration. The amounts of the precipitates formed are largely a direct function of the precipitate-forming solutes already present in the sludge water and of the amount of water present in the sludge. The amounts of solutes and water present in sludges constantly vary. These facts cause most of the difficulties encountered in trying to feed two chemicals continuously in minimum amounts. Added to these difficulties are those due to frequent smears on the filter cloth and those due to the rapid incrustation of the cloth with ferric hydrate, magnesium hydrate and carbonate of lime.

Furthermore, the chemical precipitates formed remain in the filter cake. When lime is used, the cake weight can be increased 25 to 30 per cent by the extra amount of calcium carbonate, lime soaps and ferric hydroxide. One pound of soluble CaO, if completely precipitated, will yield 1.79 lb. of $CaCO_3$ and larger quantities of fatty acid compounds of lime. One pound of ferric chloride will yield 0.66 lb. of ferric hydroxide and more of fatty acid compounds of iron. If filter cakes containing these precipitates are to be incinerated it is of importance to consider that for every ten tons of sludge solids dried and burned about two tons of inert chemical precipitate may have to be carried along as dead weight.

Elutriation, Coagulation and Sludge Filtration.—Every sludge consists of individual particles separated from other particles by water or sludge liquor which is mostly water. The particles vary enormously in size, from those in true colloidal state (sols) to agglomerates of sols that may also form large visible aggregates. The latter, on account of their amorphous and highly capillary active structures, still possess the essential surface behaviour of the sols toward electrolytes, namely, when surrounded by pure water, they can be coalesced, made less amorphous and more compact coarse aggregates by the addition of small amounts of ferric and aluminum salts. Elutriation displaces the objectionable sludge moisture by pure water.

This procedure completely eliminates the use of lime with its attendant nuisances such as provision for storing, unreliable and unsightly methods of feeding, ammonia evolution from the sludge, variations in alkalinity, increase in cake weight and ash, frequent cloth blinding and rapid cloth incrustation. At the same time elutriation materially diminishes the consumption of ferric chloride or other trivalent coagulant. The difficulties incidental to feeding any coagulant by automatic means are also diminished because after being elutriated, the sludge exhibits little variation in solid content, pH change and possesses a more uniform behaviour toward the coagulant used.

One very costly factor incidental to the chemical precipitation of sludge with ferric chloride and lime appears to be that of filter cloth. At Springfield, Ohio,[2] the amount of 6 cents per ton of sludge solids for filter cloth (including wire and labor for changing) is a costly item when translated to larger installations. With such abnormally high sludge solids the fact that one filter dressing yields only 200 tons of solids on a filter having approximately 250 sq. ft. of filter area, means that each cloth dressing is good for only about 100 hours service. This is due principally to the use of lime and is somewhat similar to the experience gained in using ferric chloride and lime on the mixture of raw and activated sludge at Hagerstown, Md. If magnesium compounds are present in the lime and the sludge moisture, the use of lime will precipitate magnesium hydroxide, which rapidly ruins filter cloths. There is always some lime carbonate and ferric hydroxide in solution with such practice. Some of these compounds remain in the cloth moisture. Precipitates of solid calcium carbonate, magnesium hydroxide

and ferric hydroxide are gradually deposited from this moisture in the fibres of the cloth.

The experience gained at Baltimore with elutriated sludges showed that one dressing lasted through an entire year of experimentation. It should be stated that the cloth used was made of wool. Nevertheless the excellent cloth life was undoubtedly due to the elimination of the presence of bicarbonates in the sludge moisture and the complete absence of the use of lime. With elutriated sludges such filter dressings should give at least 1200 hours service.

The evolution of carbon dioxide gas and foaming when stirring ferric salt solutions into elutriated sludges is entirely eliminated and the coagulation of sludge solids takes place within 30 seconds.

A further advantage is that a cheaper coagulant such as aluminum sulphate can be used.[3] On elutriated sludges good results have been obtained with this coagulant since much less gelatinous hydroxide precipitate is formed and the trivalent aluminum ion has more opportunity to coagulate the sludge solids.

When elutriated sludge is filtered, the digestion period can be definitely shortened.[3] When the sludge is elutriated one is mainly concerned with the digested solids. In order to avoid misunderstanding, the term *digested solids* refers to those solids, which during the process of normal digestion have evolved most of their gas, have ceased to float as a result of gas evolution and have consequently settled to the bottom of the digestion tank, from whence they may be withdrawn prior to dewatering. Rawn, Banta and Pomeroy have ably demonstrated that after good gas production, such solids can be withdrawn from the bottom of properly operated tanks following a 10-day digestion period.[4] Without considering at just what time in the digestion process the sludge can be elutriated and filtered to produce the best economies, the fact remains that sludge can be removed from a heated digestion chamber at any time, elutriated, coagulated with small amounts of ferric chloride and dewatered on a filter. Cameron shows that longer digestion periods are preferable at Springfield, Ohio,[2] for treatment of sludge with ferric chloride and lime.

With raw sludge that has been detained over hours and days the exact opposite holds true. Here the sludge becomes progressively more difficult to treat by chemical precipitation. Elutriation of raw sludge, Imhoff sludge, or partially and well digested sludge from heated digestion tanks, results in production of flocs that can be dewatered on modern vacuum filters with comparatively low coagulant additions. It should be noted that these conclusions are not drawn from exhaustive investigations made in Baltimore alone. A number of laboratory investigations and some actual field tests made elsewhere in the United States, Canada and in the Ruhr District in Germany on various types of digested sludges show that elutriation produces results remarkably similar to those obtained in Baltimore.

If sludge is to be incinerated, an elutriated digested sludge can be added to unelutriated primary raw sludge with considerable savings in

chemical consumption.[5] This fact makes it possible to avoid digesting all of the sludge. The odor nuisance resulting from this practice is remarkably less than when treating raw sludge alone.

The filter yield increases with the increase in solids in any sludge. Furthermore as the chemical consumption when using ferric salts and lime is largely a function of the amount of water and precipitating solutes present in the sludge, a material increase in the cost of chemical precipitation can be expected with an increase in sludge moisture. This is clearly shown in the Cameron report.[2] As a result of this argument it is logical to assume that the cost of chemical precipitation of sludges can be lessened by installing a settling or thickening tank after digestion.

Keefer and Kratz reported on such pre-thickening of digested sludge in their exhaustive paper on sludge elutriation.[6] However, with Baltimore sludges it took 18 to 24 hours to settle the sludges from about 6 to 7 per cent solids and there was very little gained.

Cameron recommends that a "fairly large storage tank for holding digested sludge be provided in addition to the digesters." The purposes of this tank are to divorce sludge filtration from sludge pumping, permit pre-thickening and insure a sludge of more uniform solid content which is distinctly advantageous to chemical precipitation.

The same size tank can be used for elutriation with very large savings in resulting filtration costs. In fact considerably more sludge solids can be elutriated in the same tank during the same time for the reason that after dilution, the solids settle several hundred times faster in this thin mixture than in the sludge drawn from a digestion tank. In a sludge drawn from a digestion tank the solids have already settled to approximately their closest spacing in a liquid of higher density than that resulting from elutriation. Elutriation also removes the adsorbed gases that otherwise render the solids lighter.

Elutriation Costs and Savings.—The citation by Cameron of Keefer's estimated costs of $2.25 per ton of sludge solids for chemicals, labor and power for elutriated sludges at Baltimore, applies only to single stage elutriation involving but two volumes of water to one of wet sludge. The estimate published by Keefer and Kratz in the *Engineering News-Record* for higher elutriation ratios shows a total operating cost for elutriation and filters, including all power, labor and coagulant of only $1.72 per ton of sludge solids.[7] The estimated coagulant cost is only 49 cents per ton, with ferric chloride at 2¼ cents per pound. This same economy can be obtained by using only three volumes of water to one of sludge in counter-current in two smaller tanks instead of one large tank.[3] It therefore should not be overlooked that this estimate relates to sludge having only about 6 per cent solids initially, *i.e.* a ratio of moisture to solids of almost 16 to 1. This cost of coagulant is almost 80 per cent lower than the July costs for ferric chloride and lime shown in the Springfield report for sludges having abnormally low moisture, *i.e.* a ratio of moisture to solids of only 4 or 5 to 1.

Savings in chemicals by elutriation will vary somewhat with the grade of water used. A water reasonably free from clay, ammoniacal compounds and bicarbonates produces the best results. For digested sludges in trickling filter plants, activated sludge or chemical precipitation, the final plant effluent is excellent. If the effluent from primary sedimentation is the only available water for elutriation, the savings in coagulant will still be very material although somewhat less than with the use of purer water. Remarkable savings in chemicals can also result from properly elutriating raw sludge with water which is practically free from disturbing compounds. However, due to the fact that elutriation can effect a reduction in the cost of heated digestion space, better total disposal economies result by adopting rapid sludge digestion and elutriation wherever vacuum filters are to be used. In plants employing vacuum filters the extra cost of an elutriation installation should be retired in 18 months by the resulting savings.

Acknowledgment

Most of the foregoing conclusions relative to elutriation were obtained at the Baltimore sewage disposal plant which is under the general supervision of B. L. Crozier, Chief Engineer of the Department of Public Works, G. E. Finck, Sewerage Engineer and C. E. Keefer, Principal Assistant Engineer. Appreciation is expressed to this organization for its interest and cooperation in this work.

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Operators' Reports and Suggestions

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GADGETS FROM INDIVIDUAL PLANTS

In the past few issues of this Journal the winning gadgets from various section competitions have been reproduced. Mr. H. E. Rhodes, Supt. Sewage Treatment, Hagerstown, Md., is the first individual to respond to the request for gadgets direct to the editor. He writes, "the only devices we have developed are probably not new or unique. However, at the request of Mr. Hall of our State Department of Health, we are forwarding them to you in hopes they may be of some help." I hope the rest of the operators, and superintendents will follow suit with those little things which they think are "not new or unique."

There is a part of this department which is still neglected and that is the *OPERATING KINKS.* Now that the gadgets are well started, how about your kinks. For example:

Rock Drillers Oil (Rape Seed Compound)

In 1930 the Decatur District purchased a new duplex plunger type sludge pump (Rex) in which the plunger also acted as an oil reservoir for lubricating the packing. The recommended lubricant was an oil compounded with rape seed oil which causes the lubricant to emulsify with water and not float away without doing its work. This lubrication of the packing was so satisfactory that we have used it also on the Barnes type plunger pumps. Each time the Barnes pumps are run some of the compounded oil is shot around the plunger from a large oil can. We find that our packing remains softer and lasts much longer. The Marlo pump also works on the same principal. Numerous plants about Illinois have concurred with us in the value of this oil. "Rock drillers oil" made by most of the good oil companies contains from 10 to 15 per cent rape seed oil and is quite satisfactory. There are other more expensive oils on the market containing 18 to 20 per cent rape seed oil. The cheaper oil seems to work satisfactorily, doubling the life of the packing.

W. D. Hatfield

VACUUM LIFT FOR FERRIC CHLORIDE

H. E. Rhodes, *Superintendent, Hagerstown, Md.*

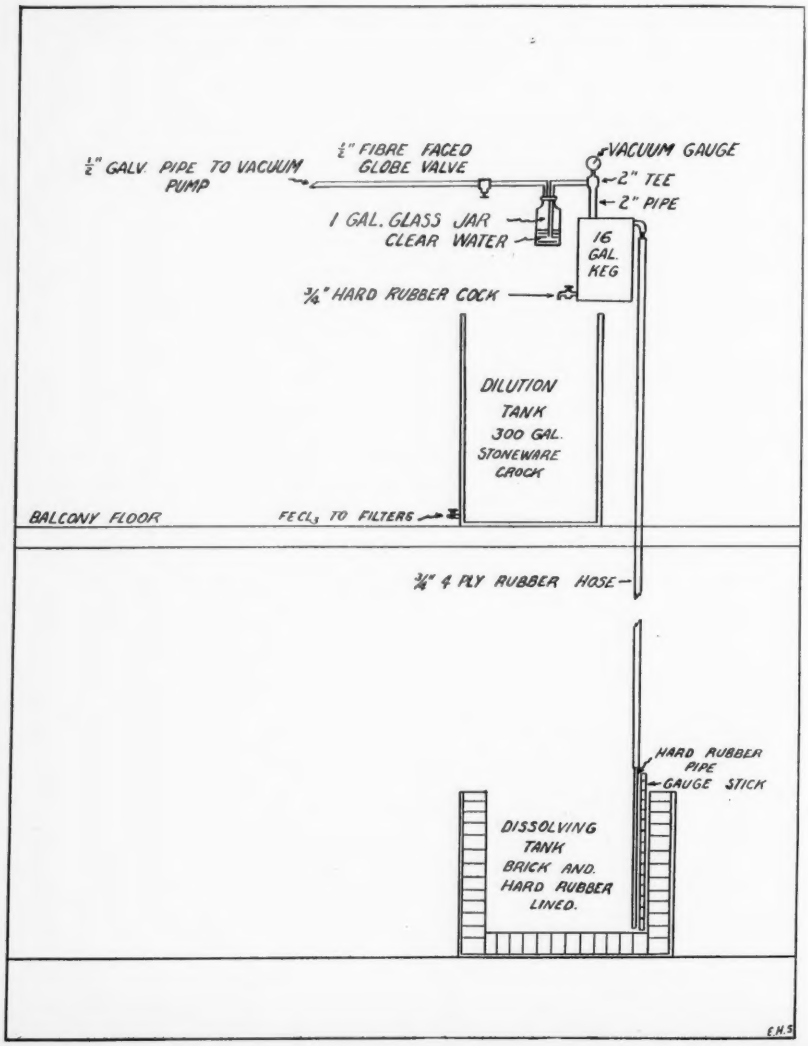
This device was designed to elevate $FeCl_3$ solution to a height of 17 ft. so the solution could feed by gravity to the point of application.

Since the solution is often handled quite hot we could not use a hard rubber pump. The other types of pump for handling this chemical were too costly, so it was decided to build a lift of our own design. The outfit illustrated in the sketch is the result of our endeavors.

How It Works

To elevate the daily required $FeCl_3$ requires the services of two men about 15 minutes per day. Man 1 stationed at the keg handles the control valves while Man 2 stationed at the dissolving tank measures the volume of liquid withdrawn. When sufficient solution has been drawn up into the keg Man 1 acting at the command of Man 2 closes the vacuum valve and opens the drain cock. As soon as the keg is empty Man 1 closes the drain cock, opens the vacuum valve and calls to Man 2 and the procedure is repeated. It is necessary to fill and empty the keg four times in order to elevate solution equal to 150 pounds of anhydrous $FeCl_3$.

The visible trap serves a double purpose. First, it washes the air (drawn from the keg to create a vacuum) of $FeCl_3$ thereby preventing these vapors entering the vacuum pump. Second, should Man 2 allow too much solution to be drawn into the keg, causing



it to overflow, Man 1 sees the trap beginning to fill and immediately closes the vacuum valve, thus no damage is done to the vacuum pump.

Vacuum for this purpose is created by the regular vacuum filtration equipment at no additional cost.

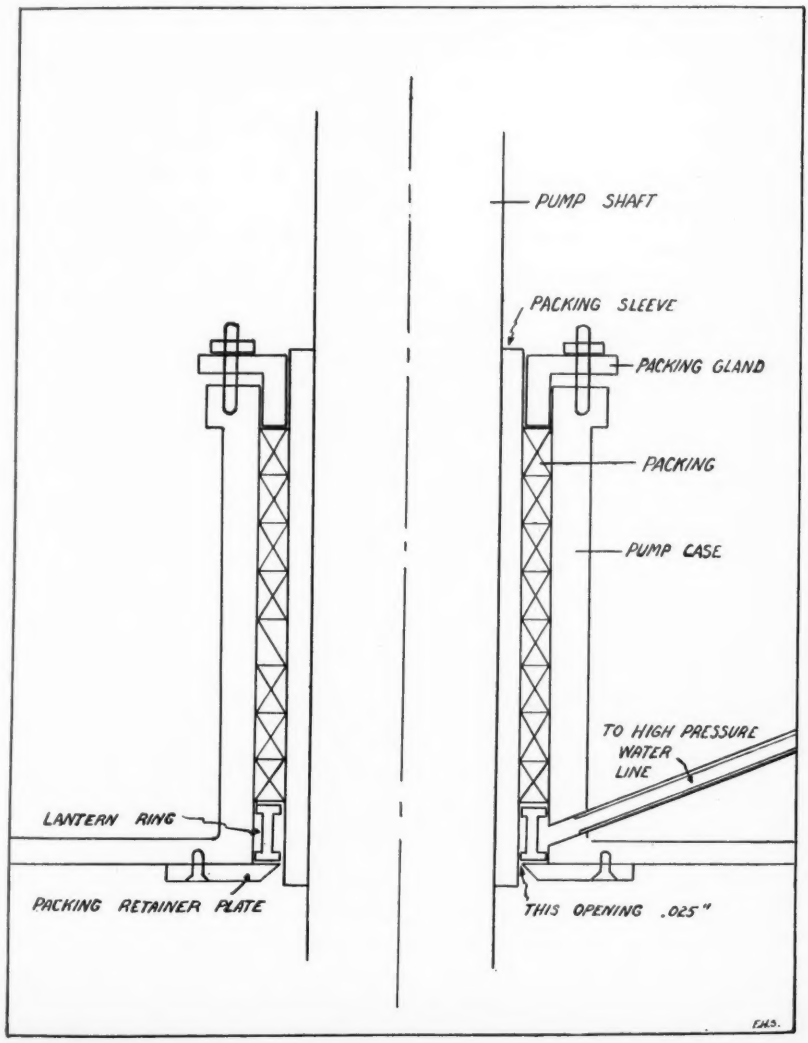
This outfit has been in use for three years, in which time it was necessary to replace the keg once.

The lift was designed and made at the plant at a cost of $11.00.

WATER SEAL FOR SLUDGE AND SEWAGE PUMPS

H. E. Rhodes, *Superintendent, Hagerstown, Md.*

After having experienced much trouble due to grit in sewage and sludge cutting out packing and sleeves in our centrifugal pumps we designed this water seal.



How It Works

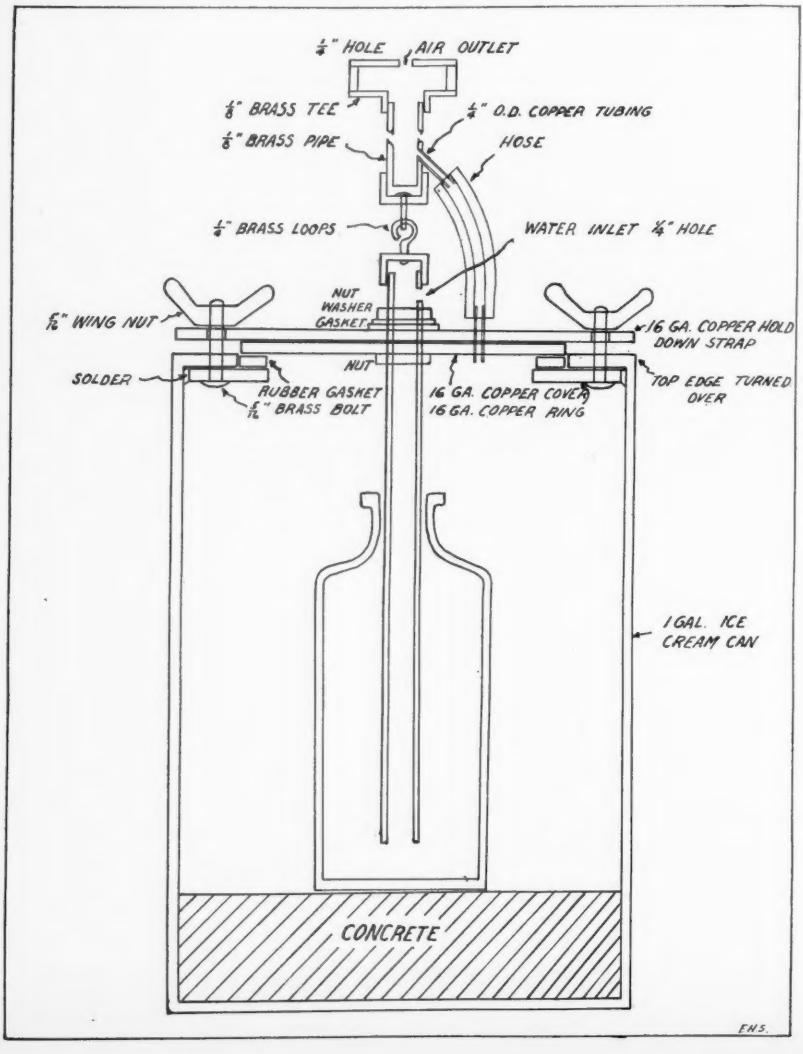
By simple rearrangement of packing and lantern ring and connection to a high pressure clear water supply a perfect water seal is secured. Water from the high pressure supply creates pressure greater than that of the pump, thus forcing all grit, etc. down and away from the packing and sleeve into the pump. Clear water completely surrounds the packing sleeve at the lantern ring and jets through the narrow (.025 in.) opening.

This device cost nothing yet has saved many packing sleeves.

CREEK SAMPLER

H. E. Rhodes, *Superintendent, Hagerstown, Md.*

This device was built to enable more accurate sample collection of creek water for D.O. determination. With the sample bottle in its indicated position and the cover



clamped tightly in place, the operator grasps the tee end of the handle in one hand leaving the tube pass between his second and third finger and holds his thumb tightly over the air outlet hole. Since the sampler is weighted it will sink readily. Upon reaching the desired depth the operator removes his thumb, allowing air to be expelled and water to enter. As shown in sketch, water first enters the bottle, which upon filling overflows into the can. This overflow is of volume sufficient to change the water in the bottle about eight (8) times, thus assuring removal of all air. This outfit has been used four years with perfect satisfaction. It was designed and made at the plant at a cost of three dollars.

EXCERPTS FROM REPORT ON OPERATION, GALESBURG, ILLINOIS, SANITARY DISTRICT, YEAR 1935

L. W. Hunt, *Chemist in Charge*

Brief Description of Sewage Treatment Works

Bar Screens.—Mechanically cleaned Dorreo bar screen with one-inch openings. Automatically operated by float controlled mercury switch.

Sewage Pumps.—Three electrically driven centrifugal pumps, two of which have a capacity of 6 m.g.d., and the third of 4 m.g.d. Total lift approximately 28 ft. Elevate screened sewage to grit chamber.

Detritor.—Mechanically cleaned Dorreo traction type. Detention period one minute.

Clarifiers.—Two 55-ft. primary settling tanks, with mechanical sludge removal. Outside water depth, 10 ft., 6 in. Dorreo traction type sludge thickener.

Sprinkling Filter.—One and one-tenth acres. Depth of crushed limestone, 6 ft. Effluent discharges into small creek.

Digestion Tanks.—Three tanks, 35 by 35 ft. by 17 ft. deep, equipped with Dorreo stirring mechanism.

Sludge Drying Beds.—Six beds, 40 by 100 ft. each, equipped with industrial railroad.

Estimated connected population, 25,000.

The first part of this report will deal with the more important general observations as well as making comparisons with former years. This will be followed by data in more detail.

Sewage Flow.—The total amount of sewage treated for the year 1935 amounted to 1114 million gallons and compares with previous years as follows:

	Total	*Daily*
1935	1114 M.G.	3.056 M.G.
1934	756 M.G.	2.069 M.G.
1933	903 M.G.	2.483 M.G.

The above data show that the amount of sewage treated in 1935 was 47% more than for 1934 and 23% more than for the year 1933. Total rainfall for the three years was as follows: 1935—42.44 in.; 1934—40.24 in.; 1933—28.09 in.

While the total for 1935 was but 2 in. more than for 1934, it was the distribution throughout the year which accounts for the increase in total sewage flow. During 1935 there were six months where the total rainfall for the month amounted to more than 3 in., while for 1934 there were but four months when it exceeded this amount.

On the basis of 25,000 connected population the 1935 flow represents a per capita flow of 122 gallons per day.

Materials Removed from Sewage by Treatment Process

Screenings.—The coarse material such as rags, sticks, tin cans, fruit skins, etc., removed amounted to 1021 cu. ft. (38 truck loads) which was 150 cu. ft. more than for 1934. The comparison with former years follows:

1935	*1934*	*1933*
1021 cu. ft.	871 cu. ft.	914 cu. ft.

This represents an increase of 17% over 1934 and 12% over 1933. The screenings weigh approximately 65 lb. per cu. ft. when removed from screen house floor and on the dry basis 6 lb. per cu. ft.

Grit.—A total of 5153 cu. ft. of grit was removed which consisted largely of sand and cinders. The removal compared with the two previous years follows:

1935	*1934*	*1933*
5153 cu. ft.	6278 cu. ft.	4403 cu. ft.

The average moisture content in the grit was 24.5% and the volatile matter was 15%, on the basis of an occasional analysis.

Floating Material.—The grease, oil and scum removed from the surface of the settling tanks amounted to 530 cu. ft. Removals of scum for the three years follow:

1935	*1934*	*1933*
530 cu. ft.	560 cu. ft.	711 cu. ft.

Fine Sewage Solids.—673,966 pounds of fine sewage solids were removed by the settling tanks. Removals for the three years are as follows:

1935	*1934*	*1933*
673,966 lb. (dry)	736,658 lb.	670,508 lb.

In terms of percentage, 1935 removal was 8.5% less than 1934 and 0.5% more than 1933. This represents a daily removal of 1818 lb. or 605 lb. per m.g. of sewage treated.

Gas Produced.—5,137,700 cu. ft. of gas were produced by the digestion of the 673,960 lb. of fine sewage solids removed by the settling tanks. The following table will show the comparison with other years:

	Daily Average
1935	14,079 cu. ft.
1934	18,807 cu. ft.
1933	13,864 cu. ft.

Gas production was 25% lower than the previous year due to more storm flow which resulted in a weaker sewage and consequently a reduction in the amount of fine sewage solids in the sewage which received treatment.

The per capita gas production was 0.56 cu. ft. per day and for 1934 it was 0.75 cu. ft. It was sufficient to supply all heating requirements, no additional fuel being purchased.

Sludge Cake Removed From Drying Beds.—922 cu. yds. of sludge cake were removed from the drying beds, 111 cu. yds. of which represented sludge withdrawn from the digestors in 1934. The year's accumulation was 811 cu. yds., the average moisture content as removed being 46.2%. Revenue from the sale of sludge as a soil conditioner was $23.25. The demand on the part of the public for sludge cake as a soil conditioner has not kept up with the supply; there being on hand approximately one year's accumulation.

Operating Costs.—The total cost of operating the treatment plant was $20,886.55. This was 4.6% higher than 1934 and 2.7% higher than 1933. The cost per million gallons of sewage treated was $18.75 which was 29.0% lower than for 1934. This decrease in cost per m.g. was due to the larger volume of sewage treated, which amounted to approximately 1.0 m.g. per day more than for 1934. The cost per capita per year on the basis of the district population of 29,000 was $0.72 and for 1934 was $0.688.

Notes on Hydrogen Sulphide Removal

The three purifying boxes were recharged a total of five times. The west digestor was drained and out of service one month beginning the middle of June. After it was placed in service the hydrogen sulphide content of the gas from this digestor was ap-

preciably higher than from the others. The reason for this appears to have been due to the temperature approaching 100° F. on one or two occasions shortly after this digestor was placed in service.

The cost of sulphide removal is shown by the following data based on gas treated by four charges:

	1935	*1934*
Cu. ft. gas treated per charge	1,279,000	1,618,500
Bushels of iron sponge per charge	20	20
Avg. grains H_2S per 100 cu. ft., raw gas	81.1	68.8
Avg. grains H_2S removed per 100 cu. ft.	60.5	44.6
Avg. grains H_2S removed per bu. sponge	38,370	36,092
Cu. ft. gas treated per bu. sponge	63,950	80,925
Bu. iron sponge per million cu. ft. gas treated	15.6	12.36
Cost of treatment per million cu. ft.	$7.50	$6.80

The cost of $7.50 per million cu. ft. of gas treated is based on the amount of gas treated by three changes of new sponge and one of the revivified or a total of four charges.

The new sponge is figured at its cost to the District of $0.55 per bushel and the revivified at one half that of the new or $0.28 per bushel.

COMBINED DIGESTOR OPERATION, 1935

	Total Solids	*Vol. Matter*
In tanks 12–31–34	270,411	98,137
Added in January	43,353	26,635
" " February	49,373	30,114
" " March	44,547	22,287
" " April	48,780	28,159
" " May	41,739	24,124
" " June	51,179	27,887
" " July	82,630	41,776
" " August	63,570	38,931
" " September	56,641	36,515
" " October	68,100	46,212
" " November	53,820	32,965
" " December	74,879	48,651
	949,022	502,393
In tanks 12–30–35	190,594	82,010
	758,428	420,383
To beds 1935	531,661	211,069
Reduction	226,767	209,314
Avg. reduction per month	18,897	
Avg. input per month	56,551	

Avg. reduction in total solids	33.4%
Avg. reduction in vol. matter	52.2%
Cu. ft. gas per lb. vol. mat. added	12.7
Cu. ft. gas per lb. vol. mat. destroyed	24.5
Avg. % solids in raw sludge	7.3
Avg. % vol. matter in raw sludge	59.6
Avg. % solids in digested sludge	13.9
Avg. % vol. matter in digested sludge	39.7
Avg. temp. of digestors	82° F.

SPRINKLING FILTER EFFICIENCY, 1935

	Avg. Daily Flow, M.G.D.	5 Day B.O.D., P.P.M.		Lb. B.O.D. Per Acre Per Day	Per cent Reduction 5 Day B.O.D.
		Clar.	Effl.		
January	3.261	77	36	1895	53.2
February	3.162	75	34	1791	54.7
March	2.840(est)	42	20	901	52.4
April	2.470(est)	51	25	950	51.0
May	1.000(est)	53	30	400	43.4
June	1.820(est)	51	23	700	54.9
July	3.298	65	24	1619	63.1
August	2.615	109	35	2151	67.8
September	2.284	125	37	2155	70.4
October	2.120	147	39	2351	73.5
November	3.897	67	24	1970	64.2
December	3.612	103	29	2807	71.8
Avg. Mo.	2.698	80	30	1641	60.0
1934 Avg.	2.069	130	43	1944	66.5
1933 Avg.	2.483	100	38	1774	59.8

NOTE: During the months of March, April, May and June all of the sewage which received primary treatment was not passed through the filter. The lower filter efficiency is due principally to the lower B.O.D. of the settled sewage.

During the months of May, June, July and August the suspended matter in the filter effluent exceeded that of the settled sewage. This prolonged "unloading" period demonstrates the need for secondary settling.

The top stone of the bed was hand "picked" during the first week of February to relieve ponding.

Editorial

A TOAST TO THE FEDERATION

This issue is dedicated primarily to the Federation, for it contains the report of the research committee, the minutes of the annual meeting, the annual report of the secretary-treasurer, a list of members and subscribers, and the roster of officers of local associations. These reports should be of unique interest to all readers of THIS JOURNAL, particularly those who helped in the organization of the Federation nearly ten years ago. Who then would have dared to predict that we would have a membership of more than 2,000 and nearly 2,500 subscribers to the JOURNAL in 1936? A reference to correspondence with Mr. Buffum in 1928 reveals that a hopeful estimate of 1,000 subscribers was submitted to him as the approximate limit of the field of circulation of the projected journal.

The growth of subscribers during 1936 was particularly gratifying, increasing from 2,063 in 1935 to 2,459 in 1936, an increase of 396 as compared with an increase of 233 during the preceding year. One of the most pleasing features of the 1936 growth was the foreign increase, as follows: Argentina, 33 new affiliates, thanks mainly to our good friend E. B. Besselievre; England, an increase from 118 in 1935 to 145 in 1936 in our two English affiliates, thanks largely to Mr. John Garner, the able President of the Institute of Sewage Purification; in addition there are 17 subscribers in England. The surprisingly large total of 162 for England creates a feeling in the Editor's mind that he must improve the JOURNAL, wherever possible, to retain the interest and subscriptions of these English friends.

Our new American affiliates are also welcome—Dakota, Georgia, and Rocky Mountain Associations. The remarkable growth of the New York Association from 321 in 1935 to 423 in 1936 is noteworthy. Increases in membership of existing associations are essential for future growth, since the U. S. is almost completely covered now by the 21 associations. Possibly the Canadian Institute can organize one or more additional associations west of Ontario. Foreign affiliates are still possible in Germany, Russia, Japan, and Australia.

Since the tenth anniversary of the founding of the Federation will occur in October, 1938, a suitable commemorative celebration has been discussed for some time by the Executive Committee and a special committee appointed by President Emerson. After considerable correspondence followed by a lengthy discussion at the annual meeting in January, it has been decided to issue a commemorative book rather than to plan for a meeting, and accordingly plans are under way for preparation of the material. We hope to announce the plans in the next issue. This book will be a suitable commemoration of the fruition of ten years' development of the Federation, which has grown so far beyond the original estimates of its founders.

Although we have had such a phenomenal growth, the future of the Federation and JOURNAL is not guaranteed unless the members and

subscribers maintain their interest and support of the JOURNAL. For years the JOURNAL has been sent to members of the Federation for a very small sum, made possible by the support of the Chemical Foundation and our advertisers, and the low overhead as compared with some technical journals. We are now almost self-supporting and Mr. Buffum wishes to be relieved of his ten-year stewardship; he is certainly entitled to this relief, with the most sincere thanks of all members of the Federation for his splendid support of the business affairs of the JOURNAL. However, the problem of finding his successor will introduce increased financial responsibilities, and the committee which is now trying to work out this problem will need the support of all members.

When we consider the growth and present standing of the Federation, it seems clear that the plans of its founders were sound. More than a year was spent in discussion of the best procedure, following the organization meeting at the Sherman House in Chicago, during the meeting of the American Water Works Association June 10, 1927. Charles A. Emerson, Jr. was appointed Chairman of the Organization Committee and he selected a committee consisting of H. P. Eddy, George W. Fuller, John H. Gregory, F. W. Mohlman, and Langdon Pearse, to head a Committee of One Hundred, selected from all parts of the United States.

After discussion during the next eight months, a meeting was called by Chairman Emerson at Trenton, N. J., March 23, 1928. Sub-committees were appointed, the Editor was elected, and an intensive search for a publisher began. Just then a fortuitous event occurred. Mr. Buffum, at the meeting of the American Chemical Society in St. Louis on April 18, 1928, asked Dr. Rudolfs if he knew of any worthy chemical project which might be supported by the Chemical Foundation. Dr. Rudolfs immediately broached the subject of the publication of a sewage works journal, and arranged for a conference with the writer, just elected Editor (in search of a publisher). Mr. Buffum was quite interested, and offered to underwrite the journal, in a letter to Mr. Emerson May 11, 1928. His offer was so unrestricted and liberal that it was accepted at once. He probably little realized that he was accepting such a long-term obligation.

Many others helped mightily in getting the new federation and the new journal launched. Mr. Streeter was responsible for the constitution and by-laws, Mr. Downes was chairman of the publication committee, and Mr. Orchard was the man who started the advertising ball rolling.

Now, after ten years, we can look back on this decade as the most momentous and progressive in the entire history of sewage disposal. How fortunate it is that the Federation and JOURNAL have spanned this outstanding period! We can look forward to even more interesting developments during the next decade.

Let us make our ten-year anniversary volume the expression of our gratification for what we have accomplished and a prophecy of what the future holds in development of the science of sewage treatment.

F. W. M.

Proceedings of Local Associations

NEW YORK STATE SEWAGE WORKS ASSOCIATION

Ninth Annual Meeting

New York City, January 21 to 23, 1937

The Ninth Annual Meeting of the New York State Sewage Works Association was held in New York City January 21 to 23, 1937, with headquarters at the Hotel McAlpin. Three hundred members and guests were registered, the largest in the history of the Association.

Charles McBreen (Orangeburg), E. J. Kilcawley (Troy), and N. L. Nussbaumer (Buffalo) were elected to the Executive Committee for a period of three years. Charles C. Agar of Albany was elected president and Fred J. Biele of Huntington vice-president. A. S. Bedell, State Department of Health, Albany, N. Y., was reappointed secretary-treasurer.

The program was arranged so that the members of the Sewage Works Association were able to attend all the Thursday sessions of the Sanitary Engineering Division of the A. S. C. E. And in like manner the members of the A. S. C. E. attended the technical sessions of the N. Y. S. S. W. A. on Friday and the joint inspection trip on Saturday.

Following the technical sessions of the A. S. C. E. on Thursday, the two groups gathered for a joint dinner, at which George Gascoigne of Cleveland, Ohio, gave an illustrated talk on sewage treatment at Cleveland.

At the general business meeting on Friday, it was noted that the Association now had a membership of 486 and that the Long Island Section had a membership of 76 and was a very active group.

A resolution with reference to pending Federal legislation on stream pollution control was unanimously adopted.

At the technical session in the morning a paper by Milton Spiegel on " Oxygen Utilization by Activated Sludge " aroused considerable interest and discussion.

At the luncheon on Friday a roll call of the affiliates of the Federation of Sewage Works Associations revealed that representatives of 13 local associations were present, including the far west, the middle west, Canada and the Argentine Republic.

Following this President Linn H. Enslow presented the Kenneth Allen Memorial Awards for 1936 to Anthony J. Fischer of New York City for the most meritorious paper of a technical and research nature, and to C. George Andersen of Rockville Centre for the best paper on sewage plant operation presented during the year. Professor Charles Gilman Hyde of the University of California was the principal speaker at the luncheon and gave a most interesting talk on "Developments in Sewage Treatment During the Past Year." At the afternoon session

Professor C. L. Walker of Cornell University presented a paper on the "Effect of Activated Carbon on Sludge Digestion," and Professor William L. Malcolm, Queens University, Kingston, Ontario, Canada, presented a paper on "Studies in the Digestion of Ground Garbage." These two papers were followed by papers on the "Progress in Sewage Treatment for New York City," by Richard H. Gould, Chief Engineer, Department of Sanitation, and "Preliminary Operations of the Coney Island Sewage Treatment Plant," by Wellington Donaldson, Sanitary Engineer, Department of Sanitation, New York City.

On Saturday through the courtesy of Deputy Commissioner W. D. Binger, Department of Sanitation, New York City, a joint inspection trip was enjoyed by some 200 persons to the Coney Island sewage treatment plant of New York City. A cavalcade of 54 city and private cars afforded comfortable transportation.

The spring meeting of the Association will be held at Utica, N. Y., June 4 and 5, at which manufacturers' exhibits will be displayed.

A. S. Bedell,
Secretary

Resolution Unanimously Adopted at Annual Meeting Held at New York City January 22, 1937

Whereas, it is now apparent that proposed Federal legislation will be presented to Congress looking toward the creation of a new Federal agency for the promotion of public health, and

Whereas, it is also apparent that this proposed Federal legislation will be presented from various points of view,

Therefore, Be It Resolved, That the New York State Sewage Works Association herewith adopt a policy to support such properly formulated legislation as will co-operate with existing State Boards of Health and other state agencies and will supplement their scope of activities rather than tend to nullify these state agencies and restrict their scope and that the Executive Committee be instructed to keep themselves well informed of the introduction and progress of such Federal legislation and to act as the agent of this Association in promoting such well formulated Federal legislation as is consistent with the above stated policy, and, furthermore, that the Executive Committee be authorized to represent the Association by resolution, by contact with Federal authorities and legislators, by appearance at public hearings, or by other means at its disposal.

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

MINUTES OF THE ANNUAL MEETING OF THE BOARD OF CONTROL

The Annual Meeting of the Board of Control of the Federation of Sewage Works Associations was held at the Engineers' Club, 32 West 40th Street, New York City, on Friday evening, January 22, 1937.

Chairman Emerson presided at the business meeting which convened immediately following a dinner attended by all members of the Board present. In the absence of H. E. Moses, Secretary-Treasurer, the Chairman appointed F. W. Gilcreas, Secretary Pro Tem. The roll call indicated the following to be present in person:

Name	*Representing*
H. G. Baity	North Carolina Sewage Works Association
Wm. W. Buffum	Member at Large
Morris M. Cohn	New York State Sewage Works Association
C. A. Emerson, Jr.	Pennsylvania Sewage Works Association
Linn H. Enslow	New York State Sewage Works Association
C. G. Gillespie	California Sewage Works Association
H. F. Gray	California Sewage Works Association
Charles Gilman Hyde	Member at Large
Arthur P. Miller	Federal Sewage Research Association
F. W. Mohlman	Editor
Earle B. Phelps	Member at Large
Wm. M. Piatt	North Carolina Sewage Works Association
Willem Rudolfs	New Jersey Sewage Conference
Earle L. Waterman	Iowa Wastes Disposal Association

Present in person, acting as proxy:

Name	*Representing*
A. S. Bedell (for F. G. Browne)	Ohio Sewage Works Conference Group
John H. Brooks, Jr. (for A. D. Weston)	New England Sewage Works Association
F. W. Gilcreas (for R. W. Van Kleeck)	New England Sewage Works Association
Guy E. Griffin (for Harry R. Hall)	Maryland-Delaware Water and Sewerage Ass'n
H. S. Hutton (for W. J. Orchard)	Member at Large
Dana E. Kepner (for L. C. Osborne)	Rocky Mountain Sewage Works Association
F. W. Mohlman (for H. W. Streeter)	Federal Sewage Research Association
R. R. Ribal (for Earnest Boyce)	Kansas Water and Sewage Works Association
W. H. Wier (for Garrett Davis and Gilbert R. Frith)	Georgia Water Works and Sewage Operators' Association

The following were represented by proxy:

Name	*Representing*
J. B. Croll	The Institute of Sewage Purification (England)
H. J. Darcey	Oklahoma Water and Sewage Conference
V. M. Ehlers	Sewage Division, Texas Section, S. W. W. A.
J. H. Garner	The Institute of Sewage Purification (England)
A. D. Hamlyn	The Institution of Sanitary Engineers—(England)
Roy M. Harris	Pacific Northwest Sewage Works Association
R. E. Koon	Pacific Northwest Sewage Works Association
J. W. McCullough	Rocky Mountain Sewage Works Association
Phil J. Martin	Arizona Sewage Works Association
Herbert A. Olson	Michigan Sewage Works Association
James R. Rumsey	Michigan Sewage Works Association
Dario Travaini	Arizona Sewage Works Association
A. H. Wieters	Iowa Wastes Disposal Association
Frank E. Willey	Kansas Water and Sewage Works Association

In the absence of the Secretary-Treasurer, his report was not presented.

Business Manager Buffum reported that the circulation of the JOURNAL was 2,459 during the year 1936. Of this total, 2,042 copies were to members of local associations, 375 to non-member subscribers, both in the United States and in foreign countries, and 42 were for gratis and exchange subscriptions. This is an increase of 396 over the previous year. Mr. Buffum also reported that the advertising income for the year 1936 amounted to $5,762.89 as compared with $5,483.28 for 1935. Mr. Buffum further stated that the Federation started exactly even at the beginning of the year, and the record of operation for 1936 shows that we came within $228.04 of splitting even.

Dr. F. W. Mohlman, Editor of the JOURNAL, presented an informal report stating that he had no suggested changes or innovations to recommend for the coming year. He stated that a possible reduction in the cost of the JOURNAL could be made by restricting the use of tables and diagrams in individual articles.

Chairman Emerson reported for the Membership Committee that two new associations had affiliated with the Federation, namely, the Rocky Mountain Sewage Works Association and the Dakota Water and Sewage Works Conference, but that there had been no further developments regarding the organization of an affiliated association in Russia.

Chairman Miller of the Publications Committee stated that he had no report to present.

Chairman Hyde of the Coordination Committee reported on the observance of the Tenth Anniversary of the organization of Sewage Works Associations, and presented for consideration the following points:

1. That there should be a suitable celebration of this Anniversary.
2. That this might take the form of a special two-three day national meeting, or
3. That it might take the form of a joint meeting with the American Society of Civil Engineers and the American Public Health Asso-

ciation in New York City in January with groups from every local association participating.

Mr. Hyde stated that although not included in the formal report of his committee, it had been suggested that the publication of a special book or manual on sewage practice would provide a fitting observance of this Anniversary.

Professor Phelps, Chairman of the Research Committee, stated that his report would appear in the March issue of the SEWAGE WORKS JOURNAL.

Mr. Piatt reported for the Finance Committee that there had been some progress toward obtaining additional advertising for the JOURNAL.

Upon suitable motion, all reports were accepted.

Plans for observance of the Tenth Anniversary were discussed generally. It was felt that financial and other difficulties would interfere with the holding of a general convention during 1938. Chairman Emerson reported that the Executive Committee of the Board of Control favored the publication of an Anniversary volume. After considerable discussion it became evident that the consensus was in favor of the Anniversary volume containing no advertising and to be sold at slightly over cost.

NEW BUSINESS

The report of the special committee on the revision of the Constitution and By-Laws was presented, read and discussed by sections and adopted unanimously on roll call with an order that it be printed in SEWAGE WORKS JOURNAL and reprinted for future reference.

It was duly voted that the Federation should issue a special volume about October, 1938, marking its Tenth Anniversary, and the Chairman was authorized to appoint a Chairman and such members of a committee as might be necessary to carry out this purpose and, with the consent of the Executive Committee, to authorize the necessary expenditures for the preliminary work of this committee. It was also determined that contributors to the volume should receive no compensation but should be given due credit for their work.

A resolution was presented from the Central States Sewage Works Association requesting the Federation to initiate a revision of the standard nomenclature for sewage and sewage treatment, originally prepared by Kenneth Allen and adopted by the American Public Health Association and the American Society of Civil Engineers.

After discussion as to best methods of procedure, Professor Phelps moved that the Chairman be authorized to consult with proper officers of the American Public Health Association and the American Society of Civil Engineers relative to formation of a joint committee to proceed with the revision of standard nomenclature for sewage and sewage treatment and that he appoint our representatives on such committee. Motion was seconded and passed.

Mr. Enslow suggested the need for a 20 per cent increase in advertising rates for the JOURNAL. It was voted to instruct the Business Manager to determine suitable action in this matter.

It was moved, seconded and voted that the Editor of the JOURNAL be authorized to submit bills for necessary office expenses to the Business Manager for payment.

Mr. Buffum suggested the appointment of a new Business Manager, stating that he had served for ten years and felt that he would like to be relieved of the duties of the position. It was moved and seconded that a committee be appointed to consider the selection of a new Business Manager and to report at the next Annual Meeting. This motion was amended to read that the committee should report by June 30. The motion passed as amended.

Chairman Emerson suggested that if there was sufficient demand for inclusion of papers appearing in the SEWAGE WORKS JOURNAL, the editors of The Industrial Arts Index would probably be glad to include that JOURNAL in those indexed.

ELECTION OF OFFICERS

The Board proceeded to the election of officers and committees for the ensuing year. It was moved and seconded to nominate all eligible present officers, members at large, and committee members whose terms expired at this meeting. This motion was passed unanimously and the Secretary Pro Tem. was instructed to cast one ballot for the election of the following:

Officers

Chairman, C. A. Emerson, Jr., New York
Vice-Chairman, Linn H. Enslow, New York
Business Manager, Wm. W. Buffum, New York

Members at Large

Wm. W. Buffum, New York City
H. W. Streeter, Cincinnati, Ohio
Wm. J. Orchard, Newark, N. J.
Chas. Gilman Hyde, Berkeley, Cal.
Earle B. Phelps, New York City

Executive Committee

C. A. Emerson, Jr., *Chairman*
Linn H. Enslow
H. E. Moses, *ex officio*
Wm. W. Buffum
Wm. J. Orchard

Constitutional Committees

Membership

H. W. Streeter, Federal, *Chairman*
A. E. Berry, Canada
R. E. Fuhrman, Missouri

Publication

A. P. Miller, Federal, *Chairman*
Earle L. Waterman, Iowa
Arthur D. Weston, New England
W. W. DeBerard, Central States
F. W. Mohlman, *ex officio*

Special Committees

Research

Earle B. Phelps, New York, *Chairman,*

Finance

Wm. M. Piatt, North Carolina, *Chairman*

Observance of 10th Anniversary

Chairman to be appointed

There being no further business, the meeting adjourned at 10:30 P.M.

Respectfully submitted,

F. W. Gilcreas,
Secretary Pro Tem.

REPORT OF SECRETARY-TREASURER, FEDERATION OF SEWAGE WORKS ASSOCIATIONS, FOR THE YEAR ENDING DECEMBER 31, 1936

The total number of affiliates in the Federation has reached twenty-five; one in Canada, two in England, one in Argentina and twenty-one in the United States. This is an increase of four over last year and includes the Georgia and Argentina groups, admitted at the 1936 Board meeting with a membership of nineteen and thirty-three, respectively, and two new associations affiliating during 1936, having been approved by the Board by means of letter ballot. These two groups are Rocky Mountain Sewage Works Association, with seven members, and Dakota Water and Sewage Works Conference admitted in December and comprising a North and South Dakota Section respectively. Both groups have made a good start and a healthy growth is anticipated.

With these additions, affiliates are now to be found in 30 of the 48 states, which states have an aggregate population of nearly 95 million, or 77 per cent of the entire population of the United States. In addition, there are the group in Canada, the two groups in England, and one in Argentina.

The gross membership of the twenty-five affiliates is 2073. With 43 dual memberships deducted, the net total is 2030; as compared with

1667 one year ago, a net increase of 363. The corresponding figure for the preceding year was 199. Membership details appear in the analytical summary next following:

	Gross Mem's'p	Dual Mems.	Gross New Mems. and Rein-statem'ts	Did not Renew Sub. 1936	Membership	
					Incr.	Decr.
Arizona S. Wks. Ass'n	8	—	3	11	—	8
California S. Wks. Ass'n	222	2	55	24	31	—
Cent. States S. Wks. Ass'n	228	3	64	15	49	—
Dakota W. & S. Wks. Conf. (New)	(Membership begins with 1937)					
Federal S. Research Ass'n	52	—	11	6	5	—
Ga. W. W. & Sew. Opers. Ass'n (New)	19	—	19	—	19	—
Iowa Wastes Disp. Ass'n	45	—	17	9	8	—
Kansas W. & S. Wks. Ass'n	40	1	21	6	15	—
Md.-Del. W. & S. Ass'n	31	1	6	4	2	—
Michigan S. Wks. Ass'n	89	—	18	14	4	—
Missouri W. & S. Conf.	90	—	59	22	37	—
New England S. Wks. Ass'n	146	6	32	21	11	—
New Jersey Sew. Conf. Group	57	—	7	6	1	—
N. Y. State S. Wks. Ass'n	423	17	131	35	96	—
N. Carolina S. Wks. Ass'n	57	—	5	22	—	17
Ohio S. Wks. Conf. Group	99	—	15	8	7	—
Oklahoma W. & S. Conf.	1	—	—	1	—	1
Pacific N. W. S. Wks. Ass'n	36	—	15	11	4	—
Pennsylvania S. Wks. Ass'n	168	12	36	19	17	—
Rocky Mt. Sew. Wks. Ass'n (New)	7	—	7	—	7	—
San. Engr. Div. of the Arg. Society of Engrs. (New)	33	—	33	—	33	—
Sew. Div.-Tex. Sec. S. W. W. A.	10	—	2	3	—	1
Can. Inst. on Sew. & San.	67	1	7	4	3	—
Inst. of Sew. Purif.—Eng.	91	—	28	8	20	—
Inst'n of San. Engrs.—Eng.	54	—	6	3	3	—
	2073	43	597	252	372	27
	43				27	
	2030 Net Mem's'p				345 Gr. Incr.	

The summary shows a total of 597 new members and reinstatements. At the same time 252 former members did not renew their memberships. Despite that fact the table shows an increase of 345 members, of whom 59 are chargeable to the new affiliates.

Annual dues of members are received by the Secretary-Treasurer, recorded and transmitted to the Business Manager. The past year these amounted to $1,824.50. These are distributed as indicated in the table on page 311.

The petty cash accounts of the Secretary-Treasurer relate chiefly to purchase of stamps and miscellaneous office expenses, amounting to $30.40 during the past year.

	1935	1936	1937	Total	Refund
Arizona S. Wks. Ass'n	$	$ 3.00	$	$ 3.00	$
California S. Wks. Ass'n	10.00	219.00		229.00	3.00
Cent. States S. Wks. Ass'n	1.50	228.00	7.00	237.00	4.00
Dakota W. & S. Wis. Conf.	(New)				
Federal S. Research Ass'n		52.00		52.00	
Ga. W. W. & Sew. Opers. Ass'n		19.00		19.00	
Iowa Wastes Disp. Ass'n	2.00	22.00		24.00	
Kansas W. & S. Wks. Ass'n		41.00		41.00	1.00
Md.-Del. W. & S. Ass'n		31.00		31.00	1.00
Michigan S. Wks. Ass'n		90.00		90.00	1.00
Missouri W. & S. Conf.	(Paid dues direct to Mr. Buffum)				
New England S. Wks. Ass'n		141.50		141.50	1.00
New Jersey Sew. Conf. Gr.		56.25	1.50	57.75	
N. Y. State S. Wks. Ass'n *	3.00	407.00		411.00	1.00
N. Carolina S. Wks. Ass'n		49.00		49.00	
Ohio S. Wks. Conf. Group		98.00		98.00	
Oklahoma W. & S. Conf.		1.00		1.00	
Pacific N. W. S. Wks. Ass'n	(Paid dues direct to Mr. Buffum)				
Pennsylvania S. Wks. Ass'n		165.00	1.50	166.50	9.00
Rocky Mt. Sew. Wks. Ass'n		3.50	10.50	14.00	
San. Engr. Div. of the Arg. Society of Engrs.		57.75		57.75	
Sew. Div. Tex. Sec. S. W. W. A.		10.00		10.00	
Can. Inst. on Sew. & San.		92.00		92.00	
Inst. Sew. Purif.—Eng.	(Paid dues direct to Mr. Buffum)				
Inst'n of San. Engr.—Eng.	"	"	"	"	"
* N. Y., 1934, $1.00	$16.50	$1786.00	$21.00	$1824.50	$21.00

On five separate occasions the Secretary-Treasurer, at the instance of the Chairman, circularized the members of the Board on matters pertaining to the business of the Federation. These comprise letter ballots relative to approval of the two new affiliates, request for possible advertisers in SEWAGE WORKS JOURNAL, questionnaire as to the Federation's Tenth Anniversary, and proposed Revision of the Constitution and By-Laws.

The Secretaries were circularized in addition to the ordinary routine matters with a request to ascertain the reaction of affiliate officers to the proposed increase of annual dues, and also asked to forward material for Dr. Hatfield's use in the new section of SEWAGE WORKS JOURNAL Operators' Reports and Suggestions. This latter request was also sent to all State Sanitary Engineers throughout the United States.

If one may judge from widespread correspondence both here and abroad, as well as by personal contact with interested men, the Federation is viewed with general approval and looked upon as a valuable agency in the field of sewage treatment. The SEWAGE WORKS JOURNAL continues to receive the well-merited approval of those interested in this line of endeavor.

H. E. MOSES,
Secretary-Treasurer

FEDERATION OF SEWAGE WORKS ASSOCIATIONS CONSTITUTION AND BY-LAWS

As Revised January 22, 1937

Constitution

ARTICLE I

NAME

The name of this organization shall be the Federation of Sewage Works Associations, hereinafter designated as the Federation.

ARTICLE II

OBJECTIVES

The objects of this Federation shall be:

SECTION 1. The advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of sewage works, through the correlation and strengthening of local, state and district sewage works associations, and the publication of a journal designed to meet the needs of persons active or interested in these fields of endeavor.

SECTION 2. The promotion and encouragement of improved waterways sanitation, through the same measures.

ARTICLE III

MEMBERSHIP

The membership of the Federation shall consist of local, state and district associations or conferences, either within or without the territory of the United States, hereinafter designated as Member Associations, whose objectives and constitutions are in harmony with the purposes of this Federation, subject to the conditions and limitations prescribed in the By-Laws of the Federation.

ARTICLE IV

ORGANIZATION

SECTON 1. The affairs of the Federation shall be conducted by a Board of Control (hereinafter designated as the Board), under such rules as the Board may determine, subject to the specific conditions of this Constitution and By-Laws.

SECTION 2. The officers of the Federation shall consist of a Chairman, a Vice-Chairman, a Secretary-Treasurer and an Editor, to be selected and to serve under conditions as provided in the By-Laws.

ARTICLE V

AMENDMENTS

Amendments to this Constitution may be made by a two-thirds vote of the total membership of the Board, notice and text of all proposed amendments having been submitted to the member associations not less than sixty days prior to the meeting at which the said amendments are to be voted upon.

By-Laws

ARTICLE I

SECTON 1. Any local, state or district sewage works association or conference, or other organization whose objectives and constitution are in harmony with those of the Federation may be granted membership in the Federation by a majority vote of the

Board; provided that the constitution of the applicant association or conference has been examined and certified by the Board as being in accord with Article III of the Constitution of this Federation; and provided, further, that certification shall be made by the association seeking admission to membership that the constitution and By-Laws of the Federation are accepted by it.

SECTION 2. Any member association may withdraw from this Federation at the end of any fiscal year by giving three months notice of such intention, provided that the dues of such member association in the Federation are fully paid up to the time of withdrawal. The member association thus withdrawing shall be entitled to its proportion of any surplus in the treasury, as determined by the proportion of the number of its active members on the date of withdrawal to the total number of active members in the combined member associations of the Federation, and shall be responsible for its proportion of any deficit, as determined in a like manner.

SECTION 3. Any member association may be excluded from this Federation, at the pleasure of the Board, for non-payment of dues, as hereinafter provided, or for any change in its constitution which may bring it into conflict with the Constitution or By-Laws of the Federation.

SECTION 4. Any change in the existing constitution or by-laws of a member association shall be reported in full to the Secretary-Treasurer of the Federation within thirty (30) days after its adoption by said member association.

ARTICLE II

DUES

SECTION 1. The dues of the member associations in the Federation shall be paid in advance at the rate of one dollar and fifty cents per annum for each person on the membership rolls of the respective member association in the United States of America and its territorial possessions on December 31st. The dues for member associations located outside these territorial limits shall be greater than the amount hereinbefore specified, by an amount to be fixed annually by the Board as equivalent to the added cost for mailing the JOURNAL to such associations as compared with the average cost for mailing to members residing within these limits. The fiscal year of the Federation shall begin on January 1st, and these dues shall be collectible on that date and shall have been paid before February 1st. If the dues of any member association shall not have been paid by February 1st, fifteen days notice of the dues in arrears shall be given to that association, after which time, if the dues remain unpaid, that association may be dropped from the rolls of the Federation, on action by the Board, as provided in Article I, Section 3, of these By-Laws.

SECTION 2. In transmitting dues to the Federation, each member association shall forward with them a certified list of the names and correct mailing addresses of all individual members of the said association who are in good standing and are entitled to receive the JOURNAL of the Federation during the ensuing year.

ARTICLE III

BOARD OF CONTROL

SECTON 1. The Board of Control, designated herein as the Board, shall consist of two representatives from each one of the member associations, together with five members-at-large selected at its first meeting by a two-thirds vote of such representatives present and voting. Thereafter the members-at-large shall be elected by the Board of Control at its annual meeting by a majority vote of the members attending said meeting, and shall serve one year or until relieved by the Board selected for the ensuing year.

SECTION 2. The members of the Board shall be appointed in a manner to be decided by each respective member association, provided, however, that the members appointed from each member association shall be so selected that their terms of office shall overlap.

SECTION 3. The duties of the Board shall consist of general supervision over all agreements and fiscal arrangements and selection of the officers of the Federation, as

hereinafter provided. The Board shall have the power to enter into agreements in behalf of the Federation and to make all arrangements, both fiscal and otherwise, for conducting the affairs and business of the Federation. A majority vote of the members of the Board present at any meeting shall be necessary for approval of all questions considered by the said Board, except amendments to the Constitution, which shall be decided by a two-thirds vote of the full Board, amendments to the By-Laws, which shall be decided by a two-thirds vote of the members of the Board present and voting at any regular meeting, and certain fiscal questions which shall be decided as hereinafter provided.

SECTION 4. The Board shall serve one year, beginning on each January 1st, or until relieved by the Board selected for the ensuing year, and shall reorganize each year on or about that date.

ARTICLE IV

OFFICERS

SECTION 1. The officers of the Federation shall be a Chairman, Vice-Chairman, Secretary-Treasurer and Editor, as provided in Article IV, Section 2, of the Constitution. The Chairman and Vice-Chairman shall be selected at the annual meeting from the membership of the Board, by a majority vote of the members attending the annual meeting. They shall serve without compensation and their term of office shall be as provided in Section 5 of this Article. The Secretary-Treasurer and Editor, either one of whom may or may not be a member of the Board, shall be selected by the Board and may receive compensation, the amount of which shall be determined by a two-thirds vote of the full Board. The Secretary-Treasurer and Editor shall be selected by a majority vote of the members of the Board present and voting at the annual meeting, and they shall be appointed and removed under regulations to be prescribed by the Board, subject to the provisions of Sections 3 and 4 of this Article.

SECTON 2. The Chairman, in addition to his ordinary duties, shall present an annual report of the transactions of the Board, which report, together with a synopsis of the general transactions of the Board, of interest to members, shall be published in the JOURNAL of the Federation. The Vice-Chairman shall perform any or all of the duties of the chairman whenever the latter may be unable, for any reason, to perform them.

SECTION 3. The Secretary-Treasurer shall be the active business agent of the Board and shall be appointed for a term of two years unless removed for cause by the Board. He shall perform the ordinary duties both of a secretary and of a treasurer. He shall receive all dues, subscriptions and other monies paid to the Federation and shall hold or dispose of the same under such rules as the Board may prescribe. He shall certify the correctness of all bills. He shall act as recorder of the Board and shall maintain a complete record of its transactions. He shall be permitted to select a Business Manager and such clerical and other assistants as may be necessary, under regulations to be prescribed by the Board. The affairs of the Federation shall be audited each year in advance of the annual meeting of the Board by a recognized accountant selected by the Board.

SECTION 4. The Editor shall be the literary agent of the Board and shall be appointed for a term of three years, unless removed for cause by the Board. He shall receive all manuscript copy, prepare it for publication, and shall be responsible for the proofreading, printing and mailing of the JOURNAL of the Federation, except in so far as he may be relieved of such duties through other arrangements made by the Board. He shall have the power to return to the author for correction, or to reject entirely, any manuscript which may be in bad condition, illegible, or clearly deficient in respect to composition, subject matter or supporting data, or otherwise conspicuously deficient or unfit for publication. He also shall have the power to reject any technical manuscript which is designed to promote commercial interests. He may appoint such editorial or clerical assistants as he may desire, subject to conditions and regulations to be prescribed by the Board.

SECTION 5. The term of office of all officers of the Federation shall become effective immediately on their selection and acceptance of office and shall continue until their successors have been selected and duly qualified.

ARTICLE V

MEETINGS

SECTION 1. The Board shall meet annually in January as promptly as is practicable after the selection of the constituent members of the said Board. The date and place of the annual meeting shall be decided at the next prior meeting by a majority vote of the members of the Board attending the said prior meeting. Due notice of the date and place of such meeting shall be sent by the Secretary-Treasurer to each member of the Board and to the Secretary of each member association at least fifteen days in advance of the scheduled date of the meeting. Special meetings of the Board may be held on call of the Chairman or on petition addressed to the Secretary-Treasurer and signed by ten or more members of the Board representing not less than seven member associations.

SECTION 2. At any meeting of the Board, a quorum shall consist of two-thirds of the duly selected members thereof. Absent members may vote by proxy, all such proxies being counted in determining a quorum.

SECTION 3. The Board is hereby empowered to authorize payment, by the Federation, of the traveling expenses of the Secretary-Treasurer and Editor to attend the Annual Meeting.

ARTICLE VI

COMMITTEES

SECTION 1. The Board shall select at its annual meeting, from among its members, an Executive Committee, consisting of the Chairman, Vice-Chairman, two other members and the Secretary-Treasurer as an ex-officio member; a Membership Committee, consisting of three members; and a Publication Committee, consisting of five members, the Editor to be ex-officio member thereof. The Chairman of the Federation shall be Chairman of the Executive Committee, and the Board shall designate the officers of the other committees. The Board may authorize such special committees as are deemed necessary and shall designate the number of members thereof. Not less than one-half of the total membership of such special committees shall be selected from members of the Board.

SECTION 2. The Executive Committee shall have full control of the management of the affairs of the Federation between meetings of the Board, subject to such actions as may be passed by the Board at its meetings. A special meeting of the Executive Committee may be called by the Chairman whenever necessary, due notice of the time and place of such meeting being given to members of the Committee by the Secretary-Treasurer. The Executive Committee shall present at each annual meeting of the Federation a budget of estimated expenses of the Federation, including those of publications, during the ensuing year. On adoption of the budget by a majority vote of the Board, the expenses of the Federation shall be limited as far as may be practicable, within the amounts prescribed in the said budget.

SECTION 3. The Membership Committee shall be charged with the duty of passing on applications for membership in the Federation and also with the encouragement of the formation of new local, state or district associations or conferences eligible for membership in the Federation. Special meetings of the Membership Committee may be called by the Chairman of the said committee whenever necessary.

SECTION 4. The Publication Committee shall have full charge, except for questions involving finances, of the policies of the Board relative to any publications for which the Federation may be responsible.

SECTION 5. The Board shall have full power to fill vacancies occurring in any office or in any of the aforesaid committees.

ARTICLE VII

PUBLICATIONS

SECTION 1. Each member association shall forward its papers and transactions to the Editor with its recommendations as to publication, and for this purpose may appoint its association editor or editorial committee. Papers submitted by individuals may be accepted for publication at the discretion of the Editor.

SECTION 2. The official publication of the Federation shall be a JOURNAL, as herein designated, which shall be published under the general supervision of the Publication Committee and under rules and arrangements prescribed from time to time by the Board, acting on recommendations by the Publication Committee. The name of the JOURNAL shall be determined by a two-thirds vote of the Board, acting on recommendations by the Publication Committee.

SECTION 3. Each member association shall notify the Secretary-Treasurer of the Federation as to the minimum number of copies of the JOURNAL which it desires to receive and shall furnish a certified mailing list for the same from time to time. Copies ordered by any member association shall be distributed to the individual members of such association, in accordance with rules to be adopted by a majority of the Board.

SECTION 4. The publications of the Federation, including the JOURNAL, shall be open to public subscription and sale, at prices to be fixed from time to time by a two-thirds vote of the Board. Additional copies of the JOURNAL, for the use of member associations, may be purchased by them at cost or at a nominal price, to be fixed by a two-thirds vote of the Board. Advertisements of an appropriate character shall be received under regulations to be prescribed by a majority of the full Board.

SECTION 5. If the total revenues received by the Federation, including dues, as prescribed in Article II of these By-Laws, and income from advertisements in the JOURNAL, should be insufficient to cover the expense of publishing the JOURNAL during a given year, the deficit may be balanced by means of a special assessment, to be proportioned among the member associations in accordance with the relative average number of copies of the JOURNAL supplied to each respective member association and individual members thereof, or by such other means as may be determined by a two-thirds vote of the full Board, having due regard for the budget limitations prescribed in Article VI, Section 2, of these By-Laws.

SECTION 6. If a manuscript submitted by a member association for publication in the JOURNAL should be rejected by the Editor, in accordance with Article IV, Section 4, of these By-Laws, the question of its acceptance may, on application of the member association from which it has been received, be reviewed by the Publication Committee, on whose recommendation the Board, by a two-thirds vote of the full membership, may order its publication if it appears to them desirable.

ARTICLE VIII

AMENDMENTS

Amendments to these By-Laws may be made by a two-thirds vote of the members of the Board present and voting at any annual meeting, notice of the proposed amendment having been given to the member associations not less than sixty days in advance of the said meeting.

Reviews and Abstracts

H. W. Streeter

STANDARD PRACTICE IN SEPARATE SLUDGE DIGESTION

Proceedings, American Society of Civil Engineers, 63, 39 (January 1937)

A Progress Report of the Sanitary Division Committee on Sludge Digestion, with Appendices of Operating Data from Grand Rapids, Michigan and Elyria, Ohio. Presented by Messrs. Samuel A. Greeley, *Chairman*, W. L. Havens, C. B. Hoover, C. E. Keefer and John F. Skinner—Committee. 68 pages, 24 tables and 14 plates.

The purpose of the report is "to state the fundamental aspects of sludge digestion and to assemble . . . information relating to the design and operation of separate sludge treatment plants." Such works represent 20–35 per cent of the total plant cost.

Characteristics of Sewage.—Data (1930) are given for 31 cities in report—for **sewage**, of total solids, suspended solids, settleable solids, B.O.D., chlorides, nitrogen and iron; and, for **sludge**, of specific gravity, moisture, pH, volatile matter and ether soluble matter. Table No. 2 is a resumé which is as follows:

Resumé of Sewage Characteristics Based on Sewage Flow of 100 G.C.D.

Item	Number of sewage works reporting	Contributing population in thousands	Parts per million			Pounds per capita per day		
			Maximum	Minimum	Average	Maximum	Minimum	Average
Total suspended solids	27	3,711	612	81	254	0.51	0.07	0.21
Volatile suspended solids	22	2,978	445	51	171	0.37	0.04	0.14
Settleable solids	19	2,144	9.3*	1.7*	5.4*	....	....	....
Settleable solids	6	1,595	476	54	20	0.40	0.04	0.17
Bio-chemical oxygen demand, 5 days, at 68° F	22	3,337	473	121	262	0.39	0.10*	0.22
pH-value	23	3,437	8.0†	6.8†	7.3†	....	....	....
Immediate chlorine demand	6	1,213	39.8	6.5	....	....	....	....
Nitrogen as free ammonia	18	1,937	34.5	6.1	14.3	0.020	0.005	0.012
Organic nitrogen	16	2,606	48.8	5.2	22.1	0.041	0.004	0.018

* Values are in cubic centimeters per liter.

† Values are not parts per million.

Characteristics of Sludge.—Well digested sludge has a uniform texture, is dark colored and dense, has a faint tarry odor and will drain readily. The sludge is alkaline and not more than 50 per cent is organic. The volatile content is 50 per cent or less of the volatile content of fresh sludge.

Characteristics of Gas.—Table III gives "American Analyses and Heat Values" of sludge digestion gas as observed at 34 plants—14 of them being American. The average composition of gas from Table III is aproximately 69 per cent CH_4, 22 per cent CO_2, 6 per cent N and 3 per cent H. The average heat value is 730 B.T.U.

Table IV furnishes data as to the collection of gas. The data include characteristics of sludge, type of digestion and temperature, pH and duration; and also the quantity of gas, total and per capita. Separate sludge digestion tanks reported for Germany show

0.41 c.f. gas per capita daily from unheated tanks, and 0.53 c.f. from heated tanks. Examples for the United States show 0.61 c.f. per capita daily from heated tanks (0.69 c.f. from activated sludge).

A preferable method of stating gas yields is in terms of the volatile matter. Thus, on the average, 7.8 cu. ft. of gas are produced for each pound of volatile solids added to the tank—or, still more preferable, as 12 cu. ft. of gas per pound of volatile solids digested.

Environmental Factors

The digestion of sludge reflects the treatment process. In addition it is affected by certain factors.

Temperature.—Temperature determines the organisms that predominate in sludge during digestion and it has a considerable influence upon the time needed for digestion. Present information indicates temperatures between 80° and 95° F., as desirable. Digestion at 110° to 130° shortens the time, but the economy is not proved.

Tabular and graphic data from several sources are given to show relationships between temperature and time of digestion. At 80° F., the data for time required for digestion range from 28 days to 58 days. Monthly average temperatures are given for six digestion tank installations. The minimum is 67° F., and the maximum 95°, but the greater number reported lie between 75° and 92°.

The choice of temperatures for operating digestion tanks involves an economic balance between the cost of heating and the cost of tank capacity. This consideration includes the factors of insulation, value of gas, method of heating, rate of heat transmission, caking on heating coils, concentration of solids, and effect on heating, heat loss from supernatant, effect of gas release on the formation of scum, the duration of winter temperatures and the need for winter storage, and finally the fact that volume for digestion and time of digestion are not directly proportional.

Reaction and Seeding.—Fresh sludge is alkaline, that from domestic sewage having a pH of 6.8 to 7.2. The reaction becomes acid within 24 hrs. Unless this condition is counteracted, as with lime or by seeding, the digestion process will be prolonged and is characterized by a high proportion of CO_2 in the gas. For the reason given, the storage of fresh solids is undesirable. Also, it is a fact, that solids high in organic matter—as from separate sewerage—tend to produce the greater acidity.

The liming of acid sludge is useful in abnormal conditions, but, for normal operation, ripe sludge is the corrective preferred to establish the more effective and odorless alkaline digestion.

The ratio between the fresh solids added and those under digestion is important. Suggestion is offered that the fresh organic solids may be from 2 per cent to 6 per cent (dry weight) of the total digesting organic solids.

Trade Wastes.—Table VI gives quantities and characteristics of the sludge that is obtained in presence of 12 kinds of trade wastes. Characteristic data are:

> Sludge from Coke Gas and Creosoting Plants—small in quantity—contains phenols and other germicides—will not itself digest, but will not affect total sewage sludge unless the industrial wastes constitute more than 2 per cent of the total volume.

Pressure.—Depth tends to produce dense sludge, but the density is not directly proportional to depth. The normal range of pressures has no effect upon digestion processes.

Moisture Content.—Moisture has less effect upon digestion than other factors. There appears to be correlation between moisture and volatile contents of sludge. For a given volatile content, activated sludge may hold greater moisture than sedimentation tank sludge.

Types of Digestion Tanks

Digestion tanks are classed as

Earth Embankment Tanks as at Birmingham, England where there are some 50 tanks with a total capacity of 340,000 cu. yd. (1,000,000 population) and from 12 to 20

feet deep. Some of the embankments are faced with concrete; later tanks have been built of brick masonry, and floating covers of concrete and pyramidal in form have been added to the original construction. Indianapolis digests sludge in pits or lagoons 7 to 10 feet deep which have a capacity of 14 cu. ft. per capita.

Open Masonry Tanks—Without Mechanical Equipment of which the Baltimore tanks are example. Open concrete tanks are used to store digested sludge at Peoria and Rockford, Ill. Those at Peoria are 130 feet in diameter; walls are 12 inches thick and lined with steel plate. Costs for open tanks are about one-third of those for controlled tanks.

Open Tanks with Stirring Mechanism.—Such tanks were developed at Rochester. Full scale works are located at Brownsville, Texas. At this plant, the tank is 35 feet in diameter and 16 feet deep. A center shaft supported from a steel truss carries top and bottom arms and the drive mechanism. The upper arms support chains for breaking the sludge. Sludge is admitted to and distributed from a central inlet well. Table VII cites 29 examples with unit capacities of from 1.0 to 4.9 cu. ft. per capita except for certain installations where extra capacity was provided for trade wastes.

Tanks with Fixed Covers—Without Stirring Mechanism.—Covers were introduced to control odors, to capture gas and to enable submergence of scum. The only American example (1930) was at Palmyra, N. J.

Covered Tanks with Stirring Equipment.—Most of these are circular. Floors drain to a center sump and with a slope of 1 on 48. Sludge is withdrawn from the sump through a pipe that is under the floor. The roof is generally of concrete and is provided with a water sealed gas dome. The stirring mechanism is similar to that described previously. In operation, the roof of the tank is under internal pressure. A table of 53 examples is given in which the unit capacity is from 1.0 to 3.7 cu. ft. per capita—except one where 8.2 cu. ft. per capita were provided for industrial wastes. The data of Table VIII include date, population; and number, shape, dimensions and volume of tanks.

Tanks with Floating Covers.—Floating covers for digestion tanks cover the whole tank surface. The cover consists of a gas tight steel plate that is supported by radial trusses that are covered with an insulated roof. At the center is a gas dome with flexible pipe outlet. Around the periphery of the cover is a vertical steel curb that forms a water seal. The cover floats on the surface of the sludge in the tank guided by rollers which bear against the tank walls.

Multi-Stage Digestion.—Multi-stage digestion consists in apportioning tanks to different phases of the digestion process and in transferring the sludge progressively from the primary to secondary and in some cases tertiary stages. The first stage is the active stage for gasification. Succeeding stages produce some gas but are generally quiescent for clarification of the supernatant. There are about 30 installations that are operated multi-stage in the United States.

Sludge Pumping Equipment

For pumping sludge use is made of Compressed Air Lifts, Pneumatic Ejectors, Diaphragm Pumps and Reciprocating and Centrifugal Pumps. For the last it is suggested that single suction, closed impeller pumps with horizontal split casing, and operating at 720–800 r.p.m. are to be preferred.

Equipment for Collecting and Utilizing Gas

Gas from sludge digestion is used for heating the digestion tanks and buildings and also in gas engines. In Germany it is frequently sold to gas plants. Table IX gives information as to usage in some 46 installations—22 of them in the United States.

Gas is collected in hoods that are mounted at the high point of the cover to the digestion tank. The size varies from 2 to 4½ feet in diameter. The hoods are water sealed and are provided with cleanout openings, with water pipe sprinkler and with a gas pipe—the latter 1¼ to 6 inches in diameter. The design and operation must be such as to exclude air as this constitutes a real hazard when admitted to explosive proportions. Floating covers automatically safeguard against entry of air. In the case of fixed covers, the gas dome may be connected to a gas holder but piping and meters must permit two

way flow of the air and the gas holder must not be allowed to become empty. Table X of the Report records data as to sizes of hoods and relations to tank area. The last is such that the area of the hood is generally about 0.005 or 0.006 of the tank area but with quite some individual variation.

Sludge Heating Equipment

Sludge in process of digestion is heated (*a*) by circulating hot water through pipe coils in the tank; (*b*) by discharging heated water or sludge liquor into the tank; (*c*) by preheating sludge. Heat is supplied from hot water or steam boilers. The former is somewhat the more efficient but does not burn gas at sufficiently high temperature to avoid corrosion if H_2S is present.

Gas Burning Power Equipment

Birmingham, England, has installed gas engines with a total of 950 H.P. of which one unit is 400 H.P. Charlotte, N. C., has one unit each of 75 and 225 H.P. Photographs of both installations are shown.

Gas engines are used for direct drive of pumps or air compressors or in conjunction with motor generator sets. Twenty (20) cubic feet of gas per horse power hour is a fair rating.

Computations

The digestion compartments of Imhoff tanks have had capacities of 1.5 to 3.5 cu. ft. per capita. Separate sludge digestion tanks are stated to require less volume. It is customary to state unit capacities as cubic feet per capita or cubic feet per million gallons of sewage daily. A better basis of design is the weight of the sewage solids recovered daily with data as to per cent volatile and per cent moisture.

The Report outlines methods and gives examples of computations for determining the necessary tank capacities and the heating requirements. Digestion tank capacities are determined for four cases—

I. Continuous operation with daily withdrawals.
II. Periodic withdrawals, incomplete digestion.
III. Periodic withdrawals, complete digestion.
IV. Unheated tanks in cold climates.

$$\text{Case I.} \quad B = \frac{0.008(2 - a_t V)Wt}{1 - w_m}$$

$$\text{Case II.} \quad B = \frac{W(t + t_1)\left[1 - \frac{a_t V}{2}\left(\frac{t + t_1}{t}\right)\right]}{62.5(1 - w_m)}$$

$$\text{Case III.} \quad B = \frac{W}{62.5}\left[\frac{t_0\left(1 - \frac{a_0 V}{2}\right)}{1 - w_m} + \frac{t_1(1 - a_0 V)}{1 - w_1}\right]$$

$$\text{Case IV.} \quad B = \frac{W}{62.5}\left[\frac{t_0\left(1 - \frac{a_0 V}{2}\right)}{1 - w_m} + \frac{(t_1 + t - t_0)(1 - a_0 V)}{1 + w_1} + \frac{t_2}{1 - w_0}\right].$$

For determination of tank capacity by permissible ratio of daily addition of volatile solids to volatile solids remaining in tank

$$B = \frac{0.016W(2 - a_t V)}{(1 - w_m)K_v(2 - a_t)}$$

a_t = fraction of volatile solids digested in time t.
B = required capacity in cubic feet.
Kv = ratio of weight of volatile solids added daily to weight of volatile solids in tank.
V = volatile fraction of solids.
W = weight in pounds.
t = adopted period of digestion-days.
t_0 = adopted period of digestion in days for 75 per cent deduction of volatile solids.
t_1 = maximum interval between sludge withdrawals.
t_2 = maximum time during which there is no digestion.
w_0 = percentage of water in entering sludge.
w_1 = percentage of water in sludge withdrawn.
$w_m = \dfrac{w_0 + w_1}{2}$.

Methods of Sludge Disposal

Sludge is disposed of as liquid sludge or as dewatered sludge and in either case digested or undigested. Liquid sludge is disposed of (*a*) by barging; (*b*) by tank truck to the land and plowing under; (*c*) by lagooning; (*d*) by broad irrigation; and (*e*) by discharge into waters of river, lake, etc. These several methods are indicated as available only to a limited extent or in particular locations.

Sludge is generally dewatered on drying beds or in vacuum filters before final disposal. Methods of disposal are—(*a*) as fertilizer; (*b*) on dumps or for filling; (*c*) by burying; (*d*) by incineration; and (*e*) by barging to open water.

Nitrogen is the chief fertilizing element of sewage sludge. This varies from about 2.0 to 6.5 per cent depending upon the treatment process. The given higher value is for the undigested and dried activated sludge at Milwaukee where some 90,000 tons are sold yearly at an (1930) average price of $18.75 per ton. Table XII gives information as to the sale of sludge as fertilizer—quantities and prices.

Operating Routine of Sludge Digestion

The suggestions of operating routine apply to separate sludge digestion tanks and to Imhoff tanks as well.

Starting Operation.—Seeding is not essential but results in establishing proper operation more quickly, and particularly in cold weather. Seeding material should be 20 to 40 per cent of the tank capacity.

Introduction of Sludge.—Seeding material should be sufficient to counterbalance acids formed from fresh sludge. Fresh (volatile) solids should be added continuously or frequently and in amount not to exceed 3 to 5 per cent of the (volatile) solids in the tank.

Use of Lime.—Liming should be an emergency matter. Results depend upon quantities and method of application.

Stirring Sludge.—There is considerable difference of opinion as to the advantage of stirring sludge. Some stirring seems necessary or desirable at least when raw sludge is added. The amount of stirring is a question. Stirring in two story tanks appears unnecessary except that some agitation may be necessary during withdrawal. Stirring is intended to liberate gas, distribute raw sludge and mix any added chemicals.

Gas—Collection, etc.—Meters should be read daily and checked occasionally. Gas lines, domes, etc., should be checked frequently for obstructions. Pressures in the system should be checked daily or more frequently. Seals should be maintained at proper levels, kept free from sludge or scum and filled with oil during freezing weather. Flame should be kept away from digestion tanks and collection system. Gas masks should be kept available.

Removal of Sludge.—Withdrawal should be slowly and uniformly. Failures to flow may be remedied mechanically or by water jets. In unheated tanks, sludge should be held in the spring as long as possible to take care of winter accumulation of partly digested material.

Removal of Scum.—Accumulation of scum in two story tank gas vents or on surface of separate digestion tanks, may cause odors, prevent free discharge of gas or clog pipe lines. Excessive scum may be counteracted by submergence grids, by stirring mechanically or by breaking by hand. Flushing with water or sludge liquor may make it possible to draw scum off through pipe lines. Ordinarily scum need be removed but yearly if at all.

Supernatant Removal.—It should be possible to draw off supernatant from different levels. It is discharged to inlet of sedimentation tanks, to digestion compartment of two story tanks or to drying beds.

Foaming Control.—Methods suggested to control foaming are (1) drawing sludge; (2) hosing; (3) circulation of supernatant liquor to foaming surface; (4) liming raw sewage or sludge; (5) chlorinating raw sewage; and (6) emptying tanks and starting anew. Accepted practice is withdrawal of sludge and maintenance of proper seeding material.

Odors.—Plant should be kept clean, free from accumulations of solids and grease. Undigested sludge should not be exposed. H_2S can be controlled by chlorination.

Analyses and Records

The efficiency of sludge digestion is measured by the reduction of volatile matter. Composite samples of digested sludge should be proportionate. Inflow and outflow of sludge are important and also the location of the sludge line. The last may be determined by pitcher pump, flat tray of fine wire mesh, and bottles on a pole.

Suggested record data are quoted below:

(1) General Data (recorded daily): Temperature of atmosphere, in degrees Fahrenheit; hot water circulated, in gallons per day; temperature of circulating water (incoming and outgoing); and temperature of sludge in tank.

(2) Incoming Sludge: Time of introducing sludge, in hours; volume added, in gallons; temperature of sludge, in degrees Fahrenheit; and analysis of sludge, daily, or for each volume added: (*a*) Percentage of total and dissolved solids; (*b*) percentage of ash and volatile matter; (*c*) pH-value and alkalinity; and (*d*) specific gravity or actual weight per gallon.

(3) Sludge Withdrawn: Volume withdrawn, in gallons; and analysis of sludge, daily or for each volume withdrawn (same as for incoming sludge).

(4) Supernatant Sludge Liquor: Volume withdrawn, in gallons; analysis of supernatant, daily, or for each volume withdrawn: (*a*) Percentage of total and dissolved solids; (*b*) percentage of ash and volatile matter; and (*c*) pH-value and alkalinity.

(5) Scum (Recorded Monthly): Thickness, in inches; volume removed, in gallons; analysis of scum: (*a*) Percentage of moisture; (*b*) percentage of ash and volatile matter; (*c*) pH-value and alkalinity; and (*d*) specific gravity.

(6) Gas: Volume, in cubic feet (recorded daily); analysis of gas (weekly): (*a*) Heat value, in British thermal units; and (*b*) percentage of CO_2, N_2, CH_4, O_2 and H_2.

Operating Results

The separate sludge digestion tanks at Grand Rapids, Michigan, and Elyria, Ohio, were operated for given periods to obtain specific information. Solids balances were made. The data include monthly averages for characteristics of sewage and quantities of sludge, supernatant and gas. Characteristics of gas and of supernatant are given. Messrs. James R. Rumsey and James R. Collier were the plant superintendents who cooperated in this work.

Special Sub Committee

The report acknowledges special assistance from a special sub committee consisting of Messrs. W. S. Mahlie, F. W. Mohlman, T. C. Schaetzle, W. F. Shepard, R. A. Allton, H. E. Babbitt, R. H. Gould, Glen D. Holmes, H. E. Miller, W. Rudolfs, W. D. Hatfield, R. T. Regester, C. K. Calvert and W. R. Copeland.

Frank Tolles

ECONOMICS OF SEWAGE TREATMENT

GEORGE J. SCHROEPFER
Minneapolis-St. Paul Sanitary District

Civil Engineering, **7**, 203 (March 1937) in report and abstract of paper presented before the Sanitary Engineering Division at the 1937 Annual Meeting, American Society of Civil Engineers.

The object of this paper by the Assistant Chief Engineer of the Minneapolis-St. Paul Sanitary District was to present general economic relationships between various methods of sewage treatment. The efficiency of treatment was measured in terms of removals of suspended solids, or B.O.D. For each of several methods of treatment, curves were plotted to show the efficiency as it varied responsive to some critical factor. The Civil Engineering abstract does not present these curves, but includes comment on each as follows:

(1) *Screens and Grit Chamber.*—Efficiency measured in terms of screen opening. With 1-inch openings and properly designed grit chambers, removal of 7 cu. ft. per m.g. may be expected.

(2) *Sedimentation* is affected by viscosity of the liquid and by specific gravity and degree of coagulation of solids. In any given case the hours detention is the critical factor. For treatment by sedimentation only, 1¼ to 1½ hours detention represents economic removal of solids, with 3–3½ hours for B.O.D. reduction. Where sedimentation is preliminary to other treatment, the economic detention is the shortest one, or, practically,—for trickling filter plants, 1½ hours;—for activated sludge treatment, ½ to 1 hour.

(3) *Trickling Filters* show overall plant efficiency of 84 per cent (Sus. Solids) and 85 per cent (5-day B.O.D.). Within limits, the efficiency is independent of the strength of the sewage or the rate of application. This points possibilities for this type of treatment.

(4) *Activated Sludge* treatment offers 91 per cent efficiency in removal of solids and 92.5 per cent in B.O.D. reduction. Four and one-half hours aeration is the economic period for normal sewage. The final settling tanks which were studied had a settling rate of 900 gallons of sewage per sq. ft. per day. Choice of the rate depends upon variations in flow and upon depth of tank with lower rates for shallow tanks.

(5) *Chemical Treatment* yields different results with change of dosage. The differences in effectiveness reported from different plants suggest careful investigation before adopting this method of treatment.

(6) *Effluent Filters* are an adjunct to other treatment and the results are a function of the method of previous treatment as well as of the strength of filter influent.

Costs, in the paper were compared in terms of total annual charges per m.g.d. per one per cent reduction in suspended solids or B.O.D. Curves are given for the several methods of treatment to show the annual costs for different sized plants—with fixed charges at 6 per cent and construction costs on the 1923–30 level. The following tabular values have been interpolated from the curves.

ANNUAL CHARGE—CENTS PER M.G. PER ONE PER CENT REDUCTION

Treatment	Normal sewage, suspended solids basis			B.O.D. basis		
	Total reduction	100 M.G.D. plant	40 M.G.D. plant	Total reduction	100 M.G.D. plant	40 M.G.D. plant
Sedimentation	56%	$.14	$.17	36%	$.217	$.268
Chemical treatment	73%	.19	.225	56%	.25	.292
Chemical treatment	91%	.262	.295	82%	.293	.323
Trickling filters	84%	.275	.29	85%	.274	.287
Activated sludge	91%	.31	.37	92%	.306	.357

The economic study of any treatment problem should be individual and may involve (*a*) degree of treatment obtained from different processes; (*b*) construction costs and rate for fixed charges; (*c*) characteristics of sewage; (*d*) seasonal variations in degree of treatment; and (*e*) available head.

FRANK TOLLES

DEOXYGENATION AND REOXYGENATION

BY C. J. VELZ

Civil Engineering, 7, 3, 203–204 (March, 1937)

It is fast becoming impressed on the public that the problem of sewage disposal extends beyond the sewer outlets and that something must be done about the menace of stream pollution. With advances in the art of sewage treatment, the remedial problem is largely one of procedure and financing. A sound and economical solution requires an evaluation of pollution liabilities and stream assets, in advance of building, to permit determining the effect on the stream of any proposed remedial program. The purpose of the paper is to present a technique of stream analysis with this end in view.

Nuisance in streams is a combination of complex noxious conditions. Although no single measure fully reflects all those conditions, the oxygen content of a stream is the best single index. Deoxygenation is a complex biochemical process influenced by time, temperature and nature of waste. Reoxygenation, no less complex, is primarily a chemical process influenced by concentration of dissolved oxygen, time, temperature, depth and turnover.

In their formula for the oxygen sag curve, Phelps and Streeter have integrated both the deoxygenation liabilities and reoxygenation assets, and defined the factors influencing rates of change in each by coefficients. Such an integrated equation has many advantages, but in certain instances a better understanding and wider application of the fundamentals can be obtained by considering deoxygenation and reoxygenation separately.

The most important asset of a stream is the natural process of reoxygenation, or absorption of atmospheric oxygen. The separate evaluation of reoxygenation as deduced by Phelps has advantages over the integrated oxygen sag formula in permitting direct evaluation of physical factors of each stream, including stream depth. It also permits application to brackish waters where tidal flow precludes use of the oxygen sag formula. Mr. Velz has developed an ingenious diagram whereby the complex diffusion equation developed by Phelps (in his New York Harbor study) can be solved graphically for any given set of conditions.

Deoxygenation in streams results from the progressive satisfaction of the oxygen demand of organic waste matters. By plotting the logarithms of oxygen demand, expressed as percentages of the initial total demand, against time for rates at different temperatures, a nest of "standard demand curves" is obtained. The lines can be utilized to estimate the relative effects of different waste-contributing population groups, each "stepped down" according to time of flow and stream temperature.

Variation in stream flow is a paramount factor in oxygen balance because of its influence on volume and on the time element in deoxygenation and reoxygenation. Although any particular oxygen balance profile is possible of reasonably exact determination from the fundamental laws governing deoxygenation and reoxygenation, load factors and run-off probabilities are not definitely predictable. By computing a series of oxygen-balance profiles over a range of loads and run-off, accurate limits of stream conditions are obtained. These limits afford a basis for measuring the necessity and effectiveness of any scheme of treatment plants designed to relieve the stream of portions of the pollution load. The subjection of various remedial combinations to such evaluation insures the proper protection to the stream and the taxpayer.

H. W. STREETER

DISINTEGRATION OF SOLID MATTER IN SEWAGE

By H. R. Lupton

The Surveyor, 91, 69–72 (January 15, 1937)

Except where river or marine currents are quite strong and reasonably constant, disintegration for a sea-outfall is invariably advantageous. Screening removes only about 5 per cent of the total polluting matter and is subject to the serious disadvantage of disposal of screenings and possible local odor nuisance. A disintegrator on the other hand can be placed underground and its existence need not be suspected by the public. Where sewage must be pumped normally, disintegrator pumps, with an efficiency of 65 per cent for large sizes, dropping to 55 per cent at about 300 gallons per minute, simplify the problem. Where there is no sewage lift the "consumption" per thousand gallons required by the disintegrator is .1 to .2 B.O.T. units for cutting to standard fineness, .15 to .3 B.O.T. units for medium fine cutting and .3 to .5 B.O.T. units for fine cutting. Under average conditions, regrinding, an inexpensive operation, must be done every three months, but where the disintegrator operates on screenings alone, regrinding must be done after about 300 hours of actual work.

Discussion.—Mr. H. C. H. Shenton (Westminster) suggested that while it was most important for the solid matter to be finely ground where disposal was by dilution, when the sewage was subsequently to be treated, "soupification" of screenings might increase the non-settleable polluting matter and make the sewage harder to treat. The addition of garbage, similarly ground, might also change the "nature of the sewage, render it more difficult to carry, calling for increased flushing, etc." Mr. Lupton replied, in regard to "soupification," that all material had to go through the purification process and the disintegrator assisted by accelerating the process.

Mr. H. R. Homewood (Bournemouth) felt that screening and disintegration of screenings was less successful than passing the entire dry weather flow through the disintegrator.

Mr. W. K. Porteous (W. K. Porteous and Co., Westminster) commented on the excellent performance of a small sized machine which he had operating on sludge alone and stressed the importance of proper clearance between the cutting edges and plate of the machine. He was of the opinion that disintegrators should not be installed alone where there was danger of sewage being washed back on beaches, or where there was insufficient current to prevent the formation of sludge banks. Mr. Homewood stated that at Bournemouth the outfall discharged into 40 feet of sea water, the dilution was enormous and the action of marine organisms was so rapid that the B. coli count was negligible throughout the bay.

Mr. D. Edwards (Brighton) stressed the proper location of outfalls, saying that the yellow streak of sewage in sea water was repugnant to visitors at seaside resorts.

Mr. V. H. Lewin (Epsom) asked if disintegration would make the sewage solids more difficult to settle in sedimentation tanks and regarding the effect of disintegration upon dewatering properties of sludge, but these were not known.

Mr. G. T. Cotterell believed there was a big advantage in disintegrating paper and other material that would tend to float and be carried back to shore.

Robert W. Kehr

THE SEPARATION AND TREATMENT OF STORM WATER SEWAGE

By H. H. Stanbridge

Presented to the North-eastern Branch of the Institute of Sewage Purification, January 23, 1937

The British Ministry of Health requirements of complete treatment of wet weather flows of sewage up to three times the dry weather flow (d.w.f.) with sedimentation for an additional equal flow have usually in the past been rigidly adhered to, though they were

meant to be more or less elastic in nature, the absence of a local nuisance from storm water overflow being the determining factor. Recently there has been a marked tendency toward increased attention being given the problem of storm water sewage treatment. This is probably due to more widespread treatment of domestic and industrial wastes which formerly masked the effect of storm water discharges; the fact that in many instances storm water overflows come into operation before stream flow increases sufficiently to provide the necessary dilution; and to the realization that, in biological sewage treatment, storm water sewage may have a beneficial effect on conditions in the plant.

In the separation of storm water flows it has sometimes been economically desirable to bypass the desired amount prior to pumping or passage through long expensive outfalls. Overflow weirs should be carefully designed to give as long a weir length as possible; to prevent sedimentation and clogging with debris; and to prevent changes in head due to clogging of screens, etc. Dip plates should be provided to trap floating material. In computing the total amount of storm sewage to be given complete treatment, 1.1 times the volume of dry weather infiltration is added to three times the volume of domestic sewage, and if trade wastes are present, either 1.1 or 2.2 times the volume of trade wastes are added, the latter figure being based on trade waste discharges occurring during a 12 hour period. Allowance is sometimes made for the variations in flow between day and night, the maximum rates to receive full treatment at Manchester being computed as follows:

Average daily d.w.f. = 32 M.G.D.
Ministry of Health requirements—(3 × domestic sewage)
+ (1.1 × trade waste) + (1 × subsoil water) = 64 M.G.D.
Average rate between 10 A.M. and 10 P.M. = 40 M.G.D.
Average rate between 10 P.M. and 10 A.M. = 24 M.G.D.
Maximum rate to receive full treatment
80 m.g.d. rate between 10 A.M. and 10 P.M.
48 m.g.d. rate between 10 P.M. and 10 A.M.

At Pudsey, a similar computation differentiating between day and night flows gave for a night rate 1.86 times the d.w.f. and for a day rate 3.33 times the d.w.f. Over a six months interval the period of operation of the separating weir, based on differentiation between day and night flow, compared to its operation whenever the flow exceeded 2.5 times the dry weather flow, is as follows:

	Non-differentiation		Differentiation	
	Times	Hours	Times	Hours
Day period	90	376.5	50	226
Night period	82	921.5	174	1400

Differentiating between day and night flows, results in a greater proportion of strong day sewages being treated, but throws a more variable load on the treatment plant.

Ministry of Health requirements for storm water overflow tanks are 6 hours detention period based on the d.w.f. with two or more tanks connected in series to operate as continuous flow tanks after becoming full of storm water. Storm water tanks with as high as 18 hours detention have been installed. The overflow or supernatant may be discharged without further treatment but is frequently returned to the plant. Sludge collected from these tanks may amount to as much as ⅓ of all that collected from the sewage. The first flush of strong sewage during a storm usually lasts about an hour and provision is sometimes made to handle these separately during light storms. In several places the additional storm water sewage required to be given sedimentation is cared for by providing sufficient primary sedimentation capacity in the treatment plant, thus obtaining the benefits of long settling periods during normal operation.

ROBERT W. KEHR

TREATMENT OF FIBERBOARD WASTE

By Foster Dee Snell

Industrial and Engineering Chemistry, 29, 238 (February, 1937)

Fiberboard is made from newspaper and rope stock. The paper stock is pulped with water and then passes through steps similar to those in a paper mill, being finally distributed to a felt. The wash water used in the operation of the plant under discussion, carrying substantial amounts of pigment and fiber, goes to a storage tank for use as makeup water and the excess not used constitutes a waste requiring treatment. Analyses showed that over 80 per cent of the solids in the waste are pigment rather than fiber. Dyestuffs and sizing materials were absent.

Composite samples of the waste were analysed for total solids, loss on ignition, oxygen consumed, color in a 25.4 mm. Lovibond cell, and suspended solids. Filtration tests showed that the color and oxygen consumed values were due to suspended solids which could be largely removed. From a practical standpoint, however, vacuum filtration of the waste was unsatisfactory. Only 2.2 gallons per square foot per hour were obtained in a 6.75 minute cycle, the rate dropped rapidly and the cake was not suitable for continuous discharge. The use of filter medium was too costly.

The material settled substantially in 24 hours, the supernatant was slightly opalescent and contained only 15 p.p.m. of suspended solids while the sludge contained over 2 per cent of solids. The total waste contained only 176 pounds of suspended solids, 155 pounds of which could be removed by 24 hour settling. Therefore, the waste was discharged to a natural lagoon about 4 feet deep and with a capacity for slightly over 24 hour detention. This was used for an extended period with only occasional cleaning to remove sludge. There was no trouble from odors and the dissolved oxygen was not dangerously reduced.

The table gives the analytical results on the raw waste, filtrate, and supernatant after 24 hour settling.

	Original p.p.m.	Filtrate p.p.m.	Supernatant from 24 hr. settling, p.p.m.
Total solids	802	668	683
Organic solids	164	94	97
Inorganic solids	638	574	586
Oxygen consumed	40	10	11
Lovibund color of 25.4 mm.	5.0 red		1.5 red
	5.0 yellow	0.5 yellow	1.0 yellow
	5.0 blue		1.0 blue

R. S. Smith

ENGLISH ADMINISTRATIVE PRACTICE IN STREAM POLLUTION CONTROL

By Willem Rudolfs

Engineering News-Record, 117, 889 (December 24, 1936)

It is generally recognized in England that the whole drainage area of a river should be placed under the control of a single authority in order to secure the proper administration of the laws pertaining to river pollution. Existing legislation, however, gives broad powers of control to various agencies. The most important of the various laws governing

stream pollution are: the Rivers Pollution Prevention Act of 1876; the Salmon and Fresh Water Fisheries Act of 1923; the Land Drainage Act of 1930; and the recent Drainage of Trade Premises Bill of 1936.

Under the Rivers Pollution Act the administration of the law was entrusted to the various sanitary authorities then existing, such as municipal corporations, improvement commissioners and local boards. Due to local influence, lack of technical assistance and the fact that any one river flowed through so many local jurisdictions, very little was accomplished. Under the Salmon and Fresh Water Fisheries Act, a board can be organized for the protection of fish life in streams of a catchment area where pollution has injured or may injure fish. These boards, some of which are very active, obtain funds from licenses sold to anglers and are more important in keeping clean streams clean than in the restoration of polluted streams. The Land Drainage Act divides the land into catchment areas for the purpose of land drainage administration. Representatives from county councils, communities, internal drainage boards and the Ministry of Agriculture are included in the personnel of these catchment boards. The possibility of combining catchment boards with water pollution boards is now being studied. The Drainage of Trade Premises Bill grants very broad powers. Any pollution by sewage (either domestic or trade wastes) that may change the pristine purity of the stream can be prevented. Minimum standards of purity are established by the Ministry of Health for the entire river basin, but local authorities may increase the requirements.

At present there are six rivers boards in operation: (1) The West Riding of Yorkshire Rivers Board which has been in operation for 43 years and has about 450 sewage treatment plants under its jurisdiction; (2) Mersey and Irwell Joint Commission; (3) Ribble Joint Commission; (4) Lee Conservancy; (5) Thames Conservancy, which has the most drastic powers and requirements; and (6) River Dee Joint Commission. Local districts, such as the West Middlesex Drainage District in which the new Mogden (London) plant is located, are formed by county councils to take care of portions of drainage areas and are operated under the general jurisdiction of a rivers board.

The organization and administration of a rivers board can be best illustrated by taking the West Riding of Yorkshire board as an example. This agency consists of thirty representatives elected by the counties, cities and boroughs in the district. The board functioning mainly as a policy agency with powers guaranteed by the county courts, compels offenders to build disposal works and also supervises the operation of the plants. When local authorities wish to build disposal works, the plans and specifications are submitted to the rivers board. The board maintains its own laboratory for the analysis of samples sent in by district inspectors and also undertakes chemical and biological research in methods of treatment, stream gaging and swimming pool supervision. All such information is made available to manufacturers and local authorities.

Loans for all sewerage and sewage treatment plants can be raised by local authorities only after they have obtained the sanction of the Ministry of Health. Applications for loans must be accompanied by plans and specifications. In this way the Ministry of Health is indirectly able to ensure that projects sponsored by local authorities are carried out on an engineering basis of economic design and construction.

In effect the relationship of the various authorities simply provides that: (1) the rivers boards are responsible for the abatement of pollution; (2) the Ministry of Health ensures sound engineering; and (3) the local authorities take care of the construction and operation. Since each local authority is represented on the rivers board or has a voice in the stream cleansing program, the objective of cooperative action can be more easily realized.

R. S. SMITH

REPORT OF THE (BRITISH) WATER POLLUTION RESEARCH BOARD FOR THE YEAR ENDED 30TH JUNE, 1936: WITH REPORT OF THE DIRECTOR OF WATER POLLUTION RESEARCH

Department of Scientific and Industrial Research. H. M. Stationery Office, London, England

In presenting this ninth of the notable series of annual reports contributed by the Board and its Director of Research, Dr. H. T. Calvert, attention is drawn to the growing seriousness of the problem of water supply in the British Isles, which has been intensified by increasing demand for water of highest quality and by a tendency for industries to adopt new processes and centralize plants, resulting in larger volumes of polluting wastes. Signs are noted of an increased recognition of the importance of devising and applying practicable methods of preventing or reducing pollution of water supplies, both surface and underground.

Close touch has been maintained with the Joint Advisory Committee on River Pollution set up in 1927 by the Ministers of Health and of Agriculture and Fisheries. Catchment Boards for purposes of land drainage have now been formed for the greater part of England and Wales. The Scottish Advisory Committee on River Pollution Prevention, appointed in 1928, has suggested in its Sixth Report (1936) that Rivers Boards should be constituted under regulations framed by the Central Authority: tidal waters and the sea being included as may be determined by the Authority.

Investigations in Progress

In the accompanying report of the Director of Water Pollution Research, brief descriptions are given of the results of investigations in progress. Those which have been concerned with sewage and industrial wastes treatment are summarized briefly as follows.

Milk Factory Effluents.—Experiments on treatment and disposal of waste waters from dairies and milk products factories have been continued at the Rothamsted Experimental Station and on a large scale at the factory of the United Dairies, Ltd., at Ellesmere, Shropshire. Two plants erected for large-scale experiments have been in operation since August, 1935. In one plant the wastes, after sedimentation, are treated by the activated sludge process. In the other plant, the settled wastes are treated biologically in two percolating filters in series; the order of the filters being changed every 3 weeks. From a crude waste with 1000 p.p.m. B.O.D., the activated sludge plant is obtaining an effluent with a B.O.D. of 20 p.p.m. Even better results are being obtained with the percolating filters, which are effecting a purification of more than 99 per cent and producing an effluent of less than 10 p.p.m. B.O.D., in which fish live.

The experiments have shown definitely that milk washings can be treated successfully by either of the two methods above noted, and likewise whey washings and mixtures of milk and whey washings. Further experiments are in progress to determine the conditions necessary to effecting purification at minimum overall cost.

Activated Sludge Process of Sewage Treatment.—As the investigations carried out by Messrs. Standfast and Wooldridge were transferred to the Department of Biochemistry at University College, London, towards the end of the year, a brief summary is given of the results thus far completed. The investigation has dealt mainly with the second stage of the activated sludge process, slow biological oxidation, as distinguished from the primary stage of clarification or absorption of organic matter by the sludge.

Utilizing an experimental glass tank equipped with forced aeration, a systematic study of the bacteriology of the process was undertaken. Samples of activated sludge and of supernatant liquid were examined bacterially and also for B.O.D., using the usual dilution method and also the Barcroft respirometer, which permitted controlled tests of small samples undiluted or with a minimum of dilution. Bacterial and protozoal growths

were studied both quantitatively and qualitatively. A special effort was made to determine experimentally the relative extent to which biochemical oxidation is induced by the action of viable bacteria, or protozoa, and by that of bacterial enzymes.

The results of these experiments have led to the conclusion that the greater part if not all of the oxidation of sewage by air is dependent on the presence of certain enzymes, such as indophenol oxidase and dehydrogenases, in the sewage or sludge. The most potent source of enzymic activity appears to be bacterial cells and many, at least, of the dead bacteria present in sludge retain a fair degree of this oxidizing activity and because of their preponderating numbers, play an important part in the oxidation of sewage. The continued activity of sludge even when saturated with sewage, which enables it to oxidize the sewage it has already absorbed, suggests that although some of the constituents of sewage may be oxidized in true solution, a proportion is oxidized after adsorption on the surface of the sludge, whether or not that sludge be suspended in an aqueous medium.

Attempts have been made to develop specialized sludges by feeding ordinary activated sludge with particular substrates over long periods. The results suggest that more active sludges can be developed in this way but this result is not invariably obtained.

Colloids in Sewage.—Earlier series of experiments on the effects of bubbles of air, oxygen, hydrogen and nitrogen in flocculating dispersed matter in sewage had suggested that the coagulation thus effected is due primarily to physical or chemical rather than to biological action. Further experiments carried out during the past year, which are described and their results presented, have indicated that an appreciable proportion of organic matter in previously sterilized sewage can be coagulated at 25° C. by the bubbling processes above noted, but that the amount coagulated is less than with unsterilized sewage. Experiments also have been made on the electrodialysis of sewage and on the effects of additions of sewage and of proteins on the coagulation of suspensions of clay by means of electrolytes. Small amounts of proteins increase the rate of coagulation, whereas greater amounts tend to protect the dispersed clay against coagulation. Similar effects, though not as definite, were produced by additions of sewage.

River Mersey Investigation.—This investigation, the object of which is to determine the effect of discharging sewage on the nature and amount of solid matter deposited in the estuary, has been continued. Hydrographic records have been studied with a view to ascertaining the changes in channel capacity in the upper estuary. Observations of the movement of submerged floats in the estuary have been made over tides of different ranges. Large numbers of samples of mud have been collected, both from the Mersey and, for comparison, from unpolluted estuaries in several other counties. The resistances of mud and other solid matter to erosion by water currents have been measured by two different methods. Information also has been obtained on the rate of sedimentation and state of aggregation of suspended matter in the estuary water. The observations are expected to be completed during 1936–37.

Gas Works Effluents.—The Liquor Effluents and Ammonia Committee of the Institution of Gas Engineers has continued its study of methods of treatment and disposal of effluents from gas works and recovery of ammonia from coal gas. This study has included experiments on the effects of sewage containing gas works effluents on the deoxygenation of water into which these wastes are discharged and on the effects of different concentrations of gas effluents on the purification of sewage by the activated sludge process. Additions of 0.4 per cent of ammoniacal liquor and 0.5 per cent of spent liquor to sewage had little effect on the rate of deoxygenation, though additions of 1 per cent to 5 per cent increased this rate. The possible toxic effects of the gas liquor on the life of a river require consideration. The results obtained from treatment of sewage containing 0.5 per cent of gas liquor were not so good as from sewage alone, though effluents of satisfactory quality were produced.

The report, 55 pages in length, contains a large amount of valuable experimental data. Appended to it is a list of 19 publications issued during the year from the work of the Board.

H. W. STREETER

REFERENCES TO SEWAGE LITERATURE

(December, 1936, and January, 1937)

American City

December, 1936.

"Good Operating Results at Iowa City Sewage Works." T. D. Kendall, pp. 53–55.
"Experience with Sewer Rentals," pp. 57–58.
"New Intercepting Sewer for La Crosse, Wisconsin," pp. 67–69.

January, 1937.

"Activated Sludge Plant Converted from Septic Tanks," pp. 49–50.

Engineering News-Record

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